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RELMAP:

A REGIONAL LAGRANGIAN MODEL OF AIR POLLUTION USER'S GUIDE

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The REgional Lagrangian Model of Air Pollution (RELMAP) is a mass conserving, Lagrangian model that simulates ambient concentrations and wet and dry depositions of SO_2, $SO_4^=$, and fine and coarse particulate matter over the eastern United States and southeastern Canada (default domain). Discrete puffs of pollutants, which are released periodically over the model's domain, are transported by wind fields and subjected to linear chemical transformation and wet and dry deposition processes. The model, which is generally run for one month, can operate in two different output modes. The first mode produces patterns of ambient concentration, and wet and dry deposition over the defined domain, and the second mode produces interregional exchange matrices over user-specified source/receptor regions. RELMAP was written in FORTRAN IV on the Sperry UNIVAC 1100/82, and consists of 19 preprocessor programs that prepare meteorological and emissions data for use in the main program, which uses 17 subroutines to produce the model simulations. The procedure necessary for running the preprocessors and the model is presented in an example execution, which also allows the user to verify his results. A statistical evaluation of the model reveals that seasonal and annual simulations of sulfur wet deposition for 1980 generally agree within a factor of two with the observed data. The model, which generally over predictes wet deposition in the spring and summer, produced Pearson correlation coefficients that range between 0.208 during autumn, and 0.689 during spring.

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AFFILIATION

Mr. Eder, Mr. Coventry, and Mr. Clark are on assignment from the National Oceanic and Atmospheric Administration, U.S. Department of Commerce.

PREFACE

One of the main research activities of the Meteorology and Assessment Division is the development, evaluation, validation, and application of models for the simulation of meteorology and air quality. Such models must be able to simulate air quality and atmospheric processes affecting the dispersion of airborne pollutants on scales that range from local to global. Within the Division, the Atmospheric Modeling Branch adapts and evaluates new and existing meteorological dispersion models, such as RELMAP, and makes these models available through EPA's User's Network for Applied Modeling of Air Pollution (UNAMAP) system. The UNAMAP system may be purchased on magnetic tape from the National Technical Information Service (NTIS).

Although attempts are made to thoroughly check out computer programs, errors are occasionally found. In case there is a need to correct or update this model or the user's guide, revisions may be obtained as they are issued by completing and sending in the form on the last page of this guide.

Comments and suggestions regarding this publication should be directed as follows:

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Technical questions regarding use of RELMAP or this user's guide may be asked by calling (919) 541-3660. Users within the Federal Government may call FTS 629-3660. Copies of this document are available from NTIS, Springfield, VA 22161.

ABSTRACT

The REgional Lagrangian Model of Air Pollution (RELMAP) is a mass-conserving, Lagrangian model that simulates ambient concentrations and wet and dry depositions of SO_2, $SO_4^=$, and fine and coarse particulate matter over the eastern United States and southeastern Canada (default domain). Discrete puffs of pollutants, which are released periodically over the model's domain, are transported by wind fields and subjected to linear chemical transformation and wet and dry deposition processes. The model, which is generally run for one month, can operate in two different output modes. The first mode produces patterns of ambient concentration, and wet and dry deposition over the defined domain, and the second mode produces interregional exchange matrices over user-specified source/receptor regions.

RELMAP was written in FORTRAN IV on the Sperry UNIVAC 1100/82, and consists of 19 preprocessor programs that prepare meteorological and emissions data for use in the main program, which uses 17 subroutines to produce the model simulations. The procedure necessary for running the preprocessors and the model is presented in an example execution, which also allows the user to verify his results.

A statistical evaluation of the model reveals that seasonal and annual simulations of sulfur wet depositions for 1980 generally agree within a factor of two with the observed data. The model, which generally over-predicts wet deposition in spring and summer, produced Pearson correlation coefficients that ranged between 0.208 during autumn and 0.689 in spring.

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SECTION 1

INTRODUCTION

PURPOSE

Ambient concentrations and depositions of pollutants are highly variable, despite the relatively small fluctuations in seasonal pollutant emissions. Differences in pollutant concentrations and depositions are attributed primarily to variability in transport, dispersion, dry deposition rates, precipitation, and chemical transformation rates.

Air pollution models that simulate these processes can predict concentration and deposition amounts on a regional (>100 km) scale. These simulations contribute to the following goals:

- a better understanding of the effects of meteorological variability,
- an identification of source regions significantly contributing to regional environmental problems,
- an estimation of the contribution of source regions to one or more receptor regions.

The REgional Lagrangian Model of Air Pollution (RELMAP) was designed to meet these goals.

HISTORY

During the mid-1970s, SRI International developed a Lagrangian puff air pollution model called EUropean Regional Model of Air Pollution (EURMAP) for the Federal Environment Office of the Federal Republic of Germany (Johnson et al., 1978). This regional model simulated monthly SO_2 and $SO_4^=$ concentrations, wet and dry deposition patterns, and generated matrices of international exchanges of sulfur for 13 countries of western and central Europe.

By the late 1970s, the U.S. Environmental Protection Agency (EPA) sponsored SRI International to adapt and apply EURMAP to eastern North America. The adapted version of this model, called Eastern North American Model of Air Pollution (ENAMAP), also calculated monthly SO_2 and $SO_4^=$ concentrations, wet and dry deposition patterns, and generated matrices of interregional exchanges of sulfur for a user-defined configuration of regions (Bhumralker et al., 1980; Johnson, 1983). ENAMAP made it possible to assess the contribution of sulfur emissions from individual states and provinces to the sulfur concentrations and depositions across the same regions, as was demonstrated during the U.S./Canadian Memorandum of Intent on Transboundary Air Pollution (Clark and Coventry, 1983).

During the early 1980s, EPA modified and improved the model to increase its flexibility and scientific credibility. By 1985, simple parameterizations of processes involving fine (diameters $< 2.5\ \mu m$) and coarse ($2.5\ \mu m <$ diameter $< 10.0\ \mu m$) particulate matter were incorporated into the model in response to impending federal standards for inhalable particulate matter. The model treats $SO_4^=$ and fine particulate matter as two exclusive entities and expects input emissions data that delineates between the two accordingly. This newest version of the model, RELMAP, is capable of simulating concentration and wet and dry deposition patterns of SO_2, $SO_4^=$, and fine and coarse particulate matter. It can also generate source-receptor matrices of SO_2, $SO_4^=$ and particulate matter for user-defined regions.

FEATURES AND LIMITATIONS

As RELMAP was designed, two conflicting goals in the development of a regional-scale model became evident. On one hand, the model was to simulate pertinent physical and chemical processes with detailed, state-of-the-art parameterizations on appropriate spatial and temporal scales. On the other hand, to be useful as a regulatory tool, the model was to require the following: (1) a small volume of input data, (2) short data processing and CPU times, and (3) low computer costs. To satisfy both goals, the pertinent physical and chemical processes were highly parameterized by using available data and current theories to create a regional pollution model capable of simulating monthly concentrations and depositions of SO_2, $SO_4^=$, and fine and coarse particulate matter. These parameterizations are representative for long-term periods (e.g., one month) and should not be interpreted as being representative for shorter periods.

RELMAP consists of 19 preprocessing programs that prepare gridded meteorological and emissions data for use in the main program. The main program uses 17 subroutines to generate the simulations. RELMAP was developed on a Sperry UNIVAC 1100/82, but the model can be run on other systems with minor changes, as described in Section 4.

The assessment of the effects of emissions of SO_2, $SO_4^=$, and fine and coarse particulate matter on concentration and deposition across downwind areas has been debated considerably over recent years. Because it is not possible to quantitatively measure the relationships, simulation models have been developed to estimate them. RELMAP represents state-of-the-art modeling for the simulation of the transport, diffusion, transformation, and deposition of these pollutants. The model produces two kinds of output: (1) spatial patterns of concentration and deposition, and

(2) interregional pollutant exchange tables that indicate how much of a pollutant in a region was emitted locally and how much originated in other specified areas.

Another feature of RELMAP is its flexibility. The values of more than fifty parameters have been defined with default values. The user can redefine these parameters by changing the default values, which are located in one subroutine. A list of the values of the default parameters and those changed by the user is generated in the printout of all model executions. A description of the parameters used in the model and the steps required to change them are described in Section 4.

The parameterizations used to simulate the complex meteorological and chemical processes occurring within the atmospheric boundary layer are only accurate to a limited degree. Chemical transformation rates used in the model are based on laboratory experiments and a limited number of field experiments. Therefore, discrepancies with real-world transformation rates may occur. Likewise, wet and dry deposition rates, derived empirically from limited site measurements under specific but limited conditions, are difficult to generalize over the spatial resolution of a regional model. As a result, there is a wide range of generally accepted values. The optimum values of most of the parameters used in the model have been investigated by numerical experimentation, but not all are known. Therefore, the user has the option of specifying other parameter values. As more knowledge is gained about the parameterizations used by the model, new values will be substituted, thereby making RELMAP a constantly evolving model.

Model simulations were originally limited to the area bounded by 25° and 55° N latitude and 60° to 105° W longitude, and these are still the default values for domain size. With these default values, the maximum number of grid cells considered at any one time by the model is 1350 (45 east-west and 30 north-south); each grid cell has a minimum spatial resolution of 1° x 1°, or roughly 10,000 km^2. The geographic domain of RELMAP may be easily changed by the user to any latitude-longitude grid of larger or smaller scale. Although the minimum temporal resolution accepted by the model is 1 h, we recommend a 2-h time step (the default value). We do not recommend using RELMAP for periods much shorter than a month because of the temporal limitations of the model's parameterizations.

As with the parameterizations, the meteorological data used by the model are limited in terms of spatial and temporal resolution. As an example, the upper air measurements used to determine the 850-mb wind patterns in the model are only made every 12 h at just 50 National Weather Service Stations throughout the entire (default) domain of the model. Added to this uncertainty are the smoothing and interpolation errors introduced when gridding these data on the spatial and temporal scales required by the model. Emissions data also contain uncertainties; estimates of total sulfur emissions (by state) in the northeastern United States can vary by as much as 15% (U.S./Canadian MOI, 1982).

In summary, there are many uncertainties in RELMAP itself and in the input data it uses. The accuracy of the model can be expected to improve as the model's parameterizations are refined. Currently, monthly values of measured and computed SO_2 and $SO_4^=$ concentrations and depositions generally agree within a factor of two (for the default domain), resulting in reasonably accurate spatial patterns.

INPUT DATA REQUIREMENTS

Input data used in RELMAP can be divided into three major categories:

- meteorological: surface and 850-mb winds, precipitation, and monthly maximum mixing heights,
- emissions: point (stack) and area sources of SO_2, $SO_4^=$, and fine and coarse particulate matter,
- terrain: land use type (after Sheih et al., 1979).

The lower winds are derived from 6-h surface reports, and the upper winds are derived from 12-h reports from approximately 50 sites within the model's default domain. Precipitation is derived from nearly 2000 hourly stations within the United States and hourly and daily stations in Canada. The emissions data, which vary with season, are broken down into either point (stack) sources or area sources. Point-source emissions are injected into the middle layer (200-700 m) of the model. Area-source emissions are injected into the lowest layer. The land use data are used in the calculation of dry deposition rates of SO_2, $SO_4^=$, and fine and coarse particulate matter. Sources for the individual input data types are given in Section 4 (Table 4.1).

All input data must be converted from their original raw forms to the gridded forms required by the model. This requires spatial interpolation of the data from reporting stations to grid cells with a user-defined (1° x 1° = default) resolution. Temporal interpolation is also required to convert the time increments of the raw data, which vary from 1 h to 12 h, into the user-defined time increment of the model (2 h = default). These conversions are accomplished by the preprocessors and are discussed in Section 4.

OUTPUT FORMATS

Output can be generated in two major formats (examples of both are in Section 5), but both formats cannot be produced by the same model run. The first format generates user-defined (45 x 30 = default) arrays of gridded values of ambient concentrations and wet and dry deposition of SO_2, $SO_4^=$, total sulfur, and fine and coarse particulate matter. The second output format, which considers the same parameters, produces source-receptor matrices. In this mode, any number of cells or group of cells can be defined by the user as a source or receptor region. Any source-receptor combination can be selected by the user, and the source regions can be different from the receptor regions.

With both output formats, depositions are given in kilograms per hectare, and concentrations are given in micrograms per cubic meter. A budget of total sulfur and particulate matter throughout each model simulation precedes the output arrays. This budget table contains total pollutant input into the model, total wet deposition and total dry deposition of the pollutant, the amount that was transported off the grid, the amount of pollutant that remained in puffs at the completion of each run, and, when applicable, the amount of pollutant transformed (e.g., SO_2 into $SO_4^=$).

The following sections of this user's guide describe the technical formulation of RELMAP in more detail, including information on the meteorological theory involved and on computer aspects of the model. Section 2 focuses on the theoretical aspects of RELMAP; Section 3 provides a statistical evaluation of the model to help the user assess the applicability of RELMAP to his particular needs. Section 4 is directed toward computer specialists and provides the information necessary for the proper installation and execution of the model. The final section provides an example of how to execute the model and permits the user to verify the execution of the model on his computer system through a comparison of results.

SECTION 2

THEORETICAL BASIS OF THE MODEL

RELMAP is a mass-conserving, regional-scale Lagrangian model that simulates ambient concentrations as well as wet and dry depositions of SO_2, $SO_4^=$, and fine and coarse particulate matter. The model performs monthly (default) simulations on a user-defined latitude-longitude grid with a user-defined degree of resolution (approximately 10,000 km^2 with the default domain size) covering the eastern two-thirds of the United States and southeastern Canada (Figure 2.1). The north-south and east-west boundaries of the model's default domain extend from 25° to 55°N latitude and from 60° to 105°W longitude, respectively. RELMAP is not restricted to this geographic domain; the user may specify a different domain, either smaller or larger than the default size, by changing PARAMETER statements in some of the subroutines. These changes are discussed in Section 4. When changing the location of the domain, the user should consider the potential effects of physical barriers (such as extensive mountain ranges) outside the default domain that have not been evaluated by RELMAP. Our analyses have thus far been confined to the default domain, and all discussions are based on our work with it or a subset of it.

RELMAP divides the atmospheric boundary layer into three layers, into which seasonal emissions are injected. As seen in Figure 2.2, the first layer is between the surface and 200 m, and the second is between 200 and 700 m. The depth of the third layer depends on the maximum mixing height, which varies (default values) from 1150 m in winter, to

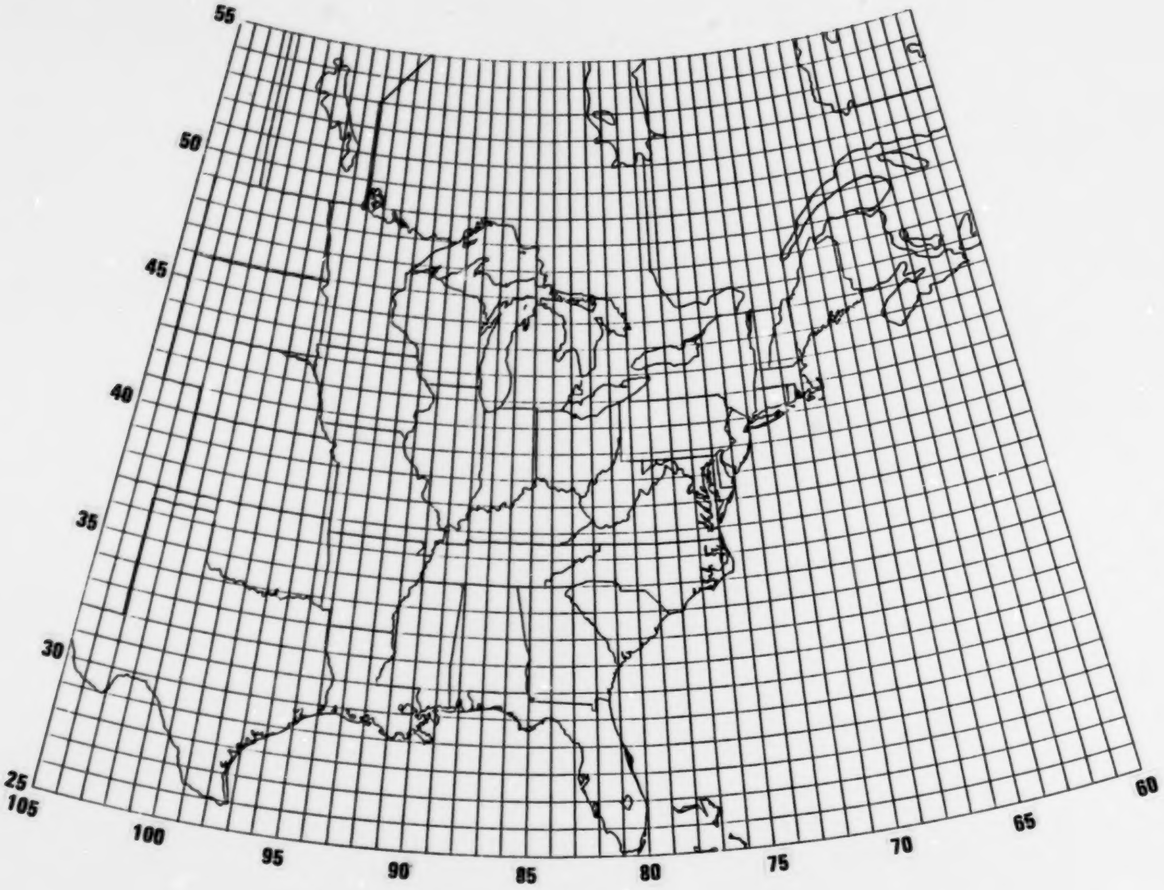

55
50
45
40
35
30
25
105
100
95
90
85
80
75
70
65
60

Figure 2.1. RELMAP's 45° x 30° latitude-longitude default domain.

1300 m in spring and fall, to 1450 m in summer (Endlich et al., 1983).

In the default mode, discrete puffs of SO_2, $SO_4^=$, and fine (excluding $SO_4^=$) and coarse particulate matter are released every 12 h for each of the 1350 grid cells that contain sources. The mass of the pollutant emitted is determined by adjusting the annual emissions by the seasonal adjustment (if known).

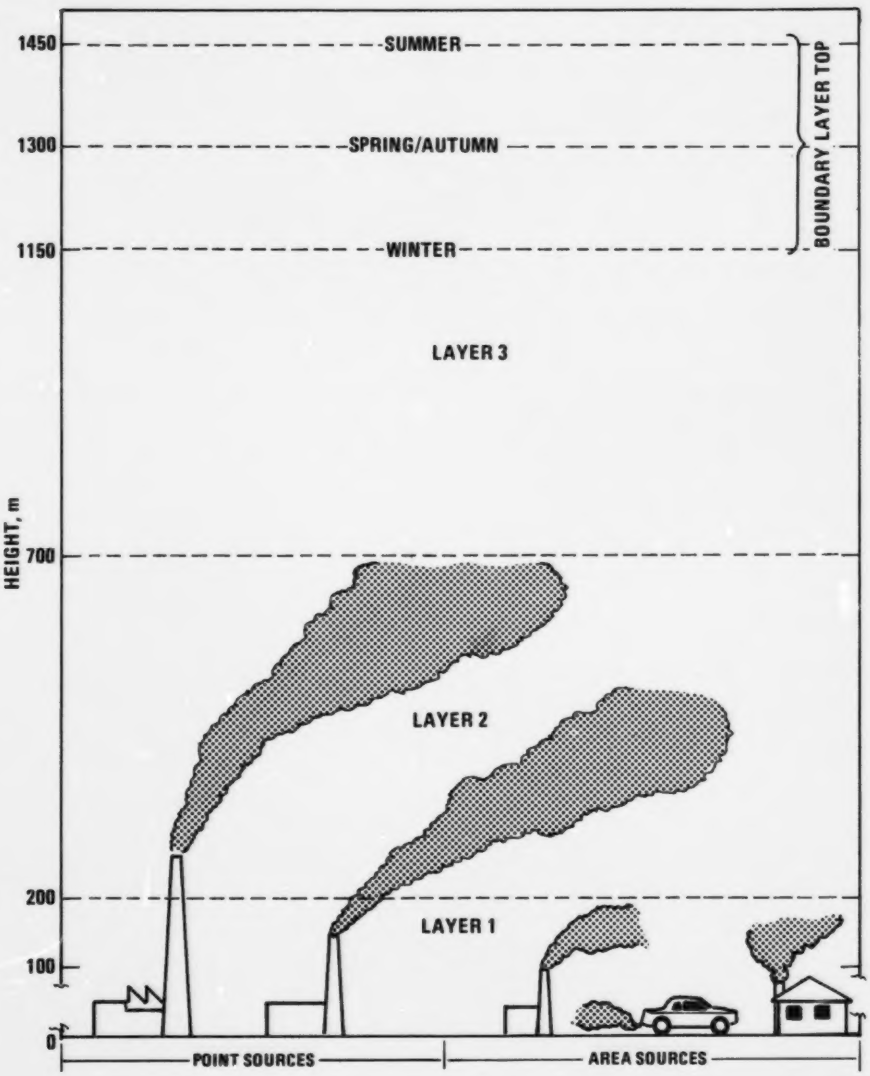

1450
SUMMER
1300
SPRING/AUTUMN
1150
WINTER
BOUNDARY LAYER TOP
LAYER 3
HEIGHT, m
700
LAYER 2
200
LAYER 1
100
0
POINT SOURCES
AREA SOURCES

Figure 2.2. Three-layer vertical profile with nighttime allocation of emissions.

Linear chemical transformation and wet and dry deposition processes are simulated as the puff is transported across the model's domain. For each time step, suspended mass pollutant and deposition of each puff are apportioned into the appropriate grid cells based on the percentage of puff over each grid cell (Figure 2.3).

The rate of change in mass of pollutants (SO_2, $SO_4^=$, and fine and coarse particulate matter) resulting from transformation and deposition is proportional to total mass and is defined through the following equations:

SO_2:
$$\frac{dM_1}{dt} = -M_1(K_t + K_{d1} + K_{w1}); \qquad (2.1)$$

$SO_4^=$:
$$\frac{dM_2}{dt} = -M_2(-3/2\ K_t + K_{d2} + K_{w2}); \qquad (2.2)$$

Fine Particulate:
$$\frac{dM_3}{d_t} = -M_3(K_{d3} + K_{w3}); \qquad (2.3)$$

Coarse Particulate:
$$\frac{dM_4}{dt} = -M_4(K_{d4} + K_{w4}), \qquad (2.4)$$

where M_i is the mass of the respective pollutants (in kilotons), t is time (in hours), K_t is the transformation rate of SO_2 into $SO_4^=$, K_d is the dry deposition rate, and K_w is the wet deposition rate. The 3/2 factor used in (2.2) represents the ratio of the molecular weights of $SO_4^=$ and SO_2. A summary of the attributes of RELMAP is provided in Table 2.1.

TABLE 2.1 SUMMARY OF ATTRIBUTES OF RELMAP*

Attribute	Description
Type	Lagrangian puff model for SO_2, $SO_4^=$, and fine and coarse particulate matter
Domain	Eastern United States and southeastern Canada, 25° to 55° N latitude and 60° to 105° W longitude
Number of layers	Three layers: 0-200 m, 201-700 m, and 701-monthly averaged maximum mixing height
Grid size	1° x 1° (approximately 10,000 km^2)
Puff frequency	12 h
Tracking increment	2 h
Horizontal diffusion	Constant expansion rate of 339 km^2/h
Vertical transport	Instantaneous, complete mixing between layers during day; no mixing across layer boundaries at night
Meteorological input data	1° x 1° grids of temporally interpolated surface and 850-mb winds, 3-h precipitation amounts, and monthly averaged maximum mixing heights
Terrain input data	Based on land use type
Transformation rate SO_2 - $SO_4^=$	Function of solar insolation
Dry deposition rate SO_2, $SO_4^=$, fine particles	Function of land use type, season, and stability index
Coarse partcles	Function of land use type, season, stability index, and particle size distribution
Wet deposition rate SO_2, $SO_4^=$, and fine and coarse particles	Function of season and precipitation rate

* All values given refer to those used in the model's default mode, except for type. The default mode for type considers only SO_2 and $SO_4^=$.

TRANSPORT AND DIFFUSION

For long-term regional-scale models such as RELMAP, turbulence-generated dispersion is not as significant as transport and removal processes (Draxler, 1984). Because of this, RELMAP parameterizes both horizontal and vertical diffusion very simply.

During the unstable regimes of midday periods, pollutants from both point and area sources become well mixed below the mixing height well before the pollutants are transported a distance comparable to the spatial resolution of the default grid. For this reason, we assume instantaneous, complete mixing within the three layers of the model during the unstable daylight hours (subroutine DAYNIT determines whether it is day or night at a puff's location). Computationally, this is achieved by dividing the total mass of the emissions between the layers in proportion to the layer depths, thereby producing equal concentrations.

After sunset, when mixing is prohibited by stable conditions, point-source and area-source emissions are injected into separate layers and confined to those layers. As Figure 2.2 illustrates, all emissions from area sources remain in Layer 1, within 200 m of the surface. Emissions from point sources are allocated into Layer 2, accounting for typical plume rise, which averages several hundred meters (Briggs, 1975).

Horizontal diffusion of the puffs in RELMAP occurs at a constant rate, so that the area of each puff increases at a rate of 339 km^2/h (default). Pollutant mass in the puff is homogeneous in the horizontal plane at all times. The value of this puff expansion rate was based on the standard deviations of the considerable vector errors associated with calculating long-range trajectories (Pack et al., 1978; Clarke et al., 1983). Nasstrom et al. (1985), who pointed out that a model-calculated, layer-averaged trajectory must consider trajectory error, have shown that the standard deviation of the trajectory error dominates the error for horizontal diffusion.

Each puff is transported in user-specified (default = 2 h; maximum = 6 h) time steps by using vertically integrated and horizontally and temporally interpolated wind fields until the puff is either transported out of the model's domain or the mass of the pollutant falls below user-defined minimum values (Figure 2.3). The pollutants in each of the three layers of a puff are transported in the same direction at the same speed. The puff remains an indivisible entity. Vertical shear is not directly considered as a component of the transport process to avoid the significant increase in computer time required to track branching puff segments. However, its effect is considered inherently in the enhanced horizontal diffusion rate of the puff.

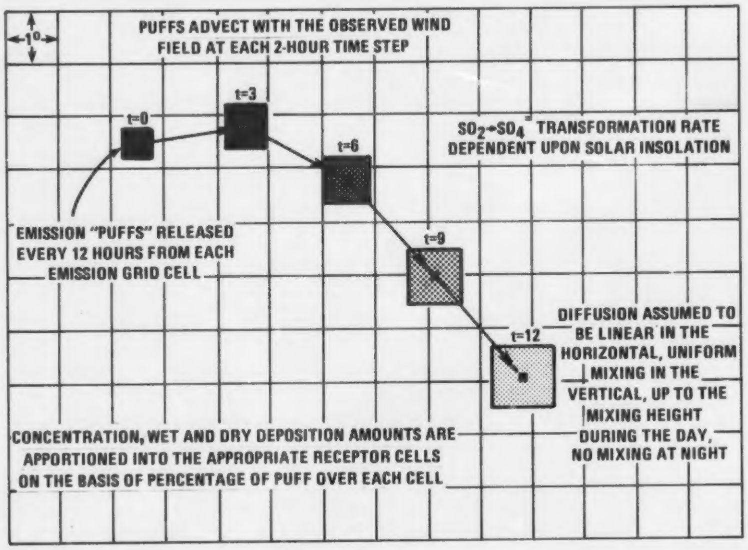

1°
PUFFS ADVECT WITH THE OBSERVED WIND FIELD AT EACH 2-HOUR TIME STEP
t=0
t=3
t=6
t=9
t=12
$SO_2 \rightarrow SO_4^=$ TRANSFORMATION RATE DEPENDENT UPON SOLAR INSOLATION
EMISSION "PUFFS" RELEASED EVERY 12 HOURS FROM EACH EMISSION GRID CELL
DIFFUSION ASSUMED TO BE LINEAR IN THE HORIZONTAL, UNIFORM MIXING IN THE VERTICAL, UP TO THE MIXING HEIGHT DURING THE DAY, NO MIXING AT NIGHT
CONCENTRATION, WET AND DRY DEPOSITION AMOUNTS ARE APPORTIONED INTO THE APPROPRIATE RECEPTOR CELLS ON THE BASIS OF PERCENTAGE OF PUFF OVER EACH CELL

Figure 2.3. Depiction of RELMAP parameterizations.

The transport velocity of the puffs is determined by integrating mass-weighted u- and v-components of the three layers, which are derived from the preprocessed wind velocities for the grid cell containing the puff's centroid (the geographic center of the puff). Wind velocity in the lowest layer is defined as surface wind velocity; wind velocity in the top layer is the 850-mb wind velocity, and wind velocity in the middle layer is a weighted average of surface (0.2) and 850-mb (0.8) wind velocities.

TRANSFORMATION RATE

RELMAP treats fine and coarse particulate matter as independent non-evolving pollutants; that is, physical and chemical transformations of fine particles to coarse particles are considered to be negligible. This premise is supported by particle size distributions obtained from ambient monitoring data (Suggs _et al_., 1981). Plots of size distributions typically indicate a bimodal distribution with peaks in the fine and coarse particle ranges and a deep gap oscillating between 1 and 5 μ m (Figure 2.4).

However, RELMAP does consider the transformation of SO_2 to $SO_4^=$. In the atmosphere, this rate varies nonexclusively with solar insolation (and thus, time of day, time of year, and latitude) and moisture content. These factors are considered by RELMAP either explicitly or implicitly. Because of the limitations of Lagrangian models, nonlinear photochemical reactions, governed by the concentrations of hydrocarbons, organic radicals, and free radicals (e.g., OH and H_2O_2) that react either directly or indirectly with SO_2, are not considered. However, the RELMAP transformation rate algorithm, based primarily on power plant plume measurements, inherently accounts for the effects of some of these reactions.

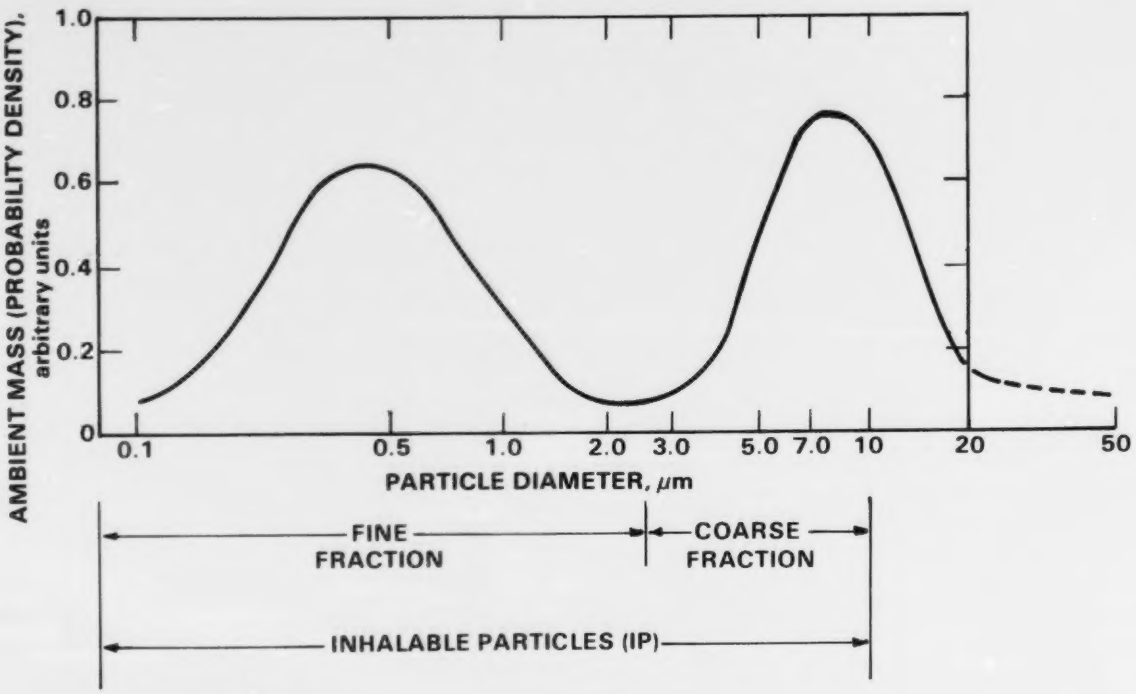


Figure 2.4. Bimodal probability distribution of particle size.

Derivation of the RELMAP Transformation Rate Algorithm

Diurnal fluctuations of the SO_2 transformation rate have been observed from power plant plume data sampled beyond a 1-h transport distance from the source (Husar et al., 1978; Forrest et al., 1981; Gillani et al., 1981; Bailey et al., 1982). Rates consistently peaked from 2.0 to 8.0 %/h near solar noon during these summer and autumn field studies. Nighttime rates, generally less than 0.5 %/h, were the lowest. However, Meagher and Olszyna (1985) detected only a slight diurnal pattern during the winter, and no diurnal pattern at all during midwinter.

Meagher et al. (1983) demonstrated seasonal variations in the transformation rate with morning data from eight plume studies. They determined that average morning rates can range from a winter low of 0.15 %/h to a summer high of 1.30 %/h. In concurrence, Altshuller (1979) predicted the noontime winter rate to be about five times less than that for summer.

The studies cited above excluded the role of moisture content, that is, data were not obtained within clouds. However, recent field studies have indicated that (1) cloud processes are important in transforming pollutants (Isaac et al., 1983), and (2) transformation rates in saturated environments are increased by an order of magnitude. Scott (1982) empirically determined that rates in precipitating clouds can range from 5.0 to 20.0 %/h in winter and from 7.0 to 40.0 %/h in summer. He concluded that the actual rates are functions of storm efficiency, cloud height, and concentrations of SO_2 and $SO_4^=$ in the mixed layer.

From these field studies, it is apparent that the transformation rate consists of at least two components: one for dry conditions (homogeneous component), and one for saturated conditions (heterogeneous component). It is also apparent from these studies that the relative contribution of these components is seasonally dependent. The RELMAP transformation rate algorithm considers both components:

$$\text{Transformation Rate} = c\ [\text{homogeneous comp.}] + d\ [\text{heterogeneous comp.}], \quad (2.5)$$

where the homogeneous component = PCTMAX [a + b log(LAT)] + RN. The relative contribution of each component, which varies seasonally via the weights c and d (discussed subsequently), were determined from climatological analyses. The variables in (2.5) are defined in Table 2.2.

TABLE 2.2. VARIABLES IN EQUATIONS 2.5 AND 2.6

Term	Description
a, b	Monthly varying, empirically derived constants used to determine the maximum homogeneous transformation rate at solar noon
c, d	Monthly varying, empirically derived constants used as weights for the homogeneous and heterogeneous transformation rate components, respectively
PCTMAX	Percent of the daily maximum transformation rate at any hour; varies with hour, day, length of day, latitude, and solar declination
LAT	Latitude, in degrees (positive in the northern hemisphere)
RN	Minimum transformation rate regardless of time or season (0.2 %/h), as estimated by Meagher _et al._ (1978)
HR	Time of day (h), where 12 always represents solar noon (i.e., the sun reaches its zenith)
DAYLEN	Length of day (h) as determined from time of year, latitude, and solar declination

The homogeneous transformation rate for any hour is obtained by multiplying PCTMAX by the maximum transformation rate at solar noon [a + b log(LAT)]. The values of PCTMAX, ranging from 0 at night to 1 at solar noon, are determined as follows:

$$\text{PCTMAX} = [\cos [2\pi (\text{HR} - 12)/\text{DAYLEN}] + 1]/2, \qquad (2.6)$$

for (12 - DAYLEN/2) < HR < (12 + DAYLEN/2); otherwise, PCTMAX = 0.

To minimize computational time in RELMAP, values of DAYLEN were defined as the length of the day at 40° N latitude (the center of the model's default domain) for the middle of each month (Table 2.3). The following equations from Duffie and Beckman (1974) were used to calculate the value of DAYLEN for each month.

$$\text{DAYLEN} = 0.133[\cos^{-1}[-\tan(\text{LAT}) \times \tan(\text{SOLDEC})]], \tag{2.7}$$

where SOLDEC, solar declination, is defined as follows:

$$\text{SOLDEC} = 23.45[\sin[360.0 \times (284.0 + \text{DAY})/365.0]], \tag{2.8}$$

where DAY is the Julian day of the year.

TABLE 2.3. AVERAGE LENGTH OF DAY (h) AT 40° N LATITUDE FOR THE MIDDLE OF EACH MONTH

Month	Length	Month	Length
January	9.5	July	14.5
February	10.4	August	13.5
March	11.7	September	12.2
April	13.0	October	10.8
May	14.2	November	9.7
June	14.8	December	9.1

The constants a and b of (2.5) were derived from Altshuller's (1979) midday rate curves for "clean" tropospheres at various latitudinal bands and from Meagher and Olszyna's (1985) algorithm derived from hourly power plant plume measurements from 11 separate studies. Their algorithm is loosely based on the diurnal and annual variation in clear-sky solar insolation. We derived the constants in the following manner.

First, we derived simple logarithmic expressions for each of Altshuller's curves for four months (one month of each season). Each expression was of the form, a + b log(LAT). Next, for each of the four months, the a's were adjusted upwards, so that Altshuller's midday rates at 35° N latitude (under-estimated for polluted tropospheres) equaled the daily maximum rate measured by Meagher and Olszyna at 35° N latitude. Values of the constants for the remaining eight months were based on seasonal patterns in the transformation rates of Meagher and Olszyna. Table 2.4 lists the constants for each month.

TABLE 2.4. EMPIRICAL CONSTANTS FOR THE MONTHLY MAXIMUM DRY COMPONENT OF THE TRANSFORMATION RATE

Month	a	b	Month	a	b
January	2.91	-0.76	July	7.62	-1.36
February	3.12	-0.75	August	7.36	-1.34
March	4.82	-1.09	September	6.80	-1.31
April	7.06	-1.53	October	5.80	-1.24
May	7.32	-1.40	November	5.02	-1.19
June	7.65	-1.37	December	2.86	-0.71

The heterogeneous component in 2.5 accounts for the more rapid incloud transformation process. The magnitude of this component was predicted by Scott (1982) through his theoretical algorithm by using a range of values for the pertinent parameters (e.g., cloud water removal efficiency, storm efficiency, and ambient SO_2 concentration). For winter simulations, the heterogeneous component varied from 0 to 20 %/h, and for summer simulations it varied from 7 to 40 %/h. Scott noted that the rate drops to 0 %/h when the cloud droplets freeze and that the summer rates do not exceed 20 %/h if only storms with low-level outflow at the back side are considered.

Based on this information, RELMAP rates for the heterogeneous component were arbitrarily defined as 7 %/h for winter, 11 %/h for spring and autumn, and 15 %/h for summer. The intent here was to account for the seasonal variations of the heterogeneous component.

The transformation component weights c and d in (2.5) were derived from seasonal climatological data for precipitation events (Thorp, in press). He used hourly precipitation data for August 1977 through January 1980 at 89 first-order weather stations in the northeastern United States to determine average precipitation event frequency and duration. From these statistics, we determined the average percentages of months when precipitation occurred at any one station. These monthly percentages were defined as the d weights for the heterogeneous component of the transformation rate. The monthly c weights were defined as the difference between unity and the d weights.

Figures 2.5 and 2.6 illustrate the relationship between the composite transformation rate and latitude, time of day, and time of year. Note that these transformation rates represent hourly rates averaged over periods of a month. Hourly rates for a single day would probably deviate from the mean.

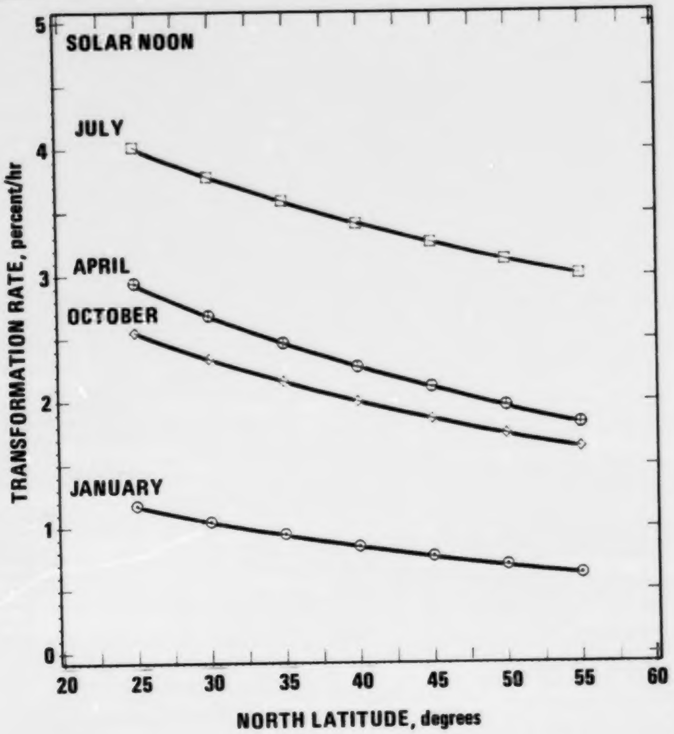


Figure 2.5. Latitudinal variation in the composite transformation rate of SO_2 to $SO_4^=$.

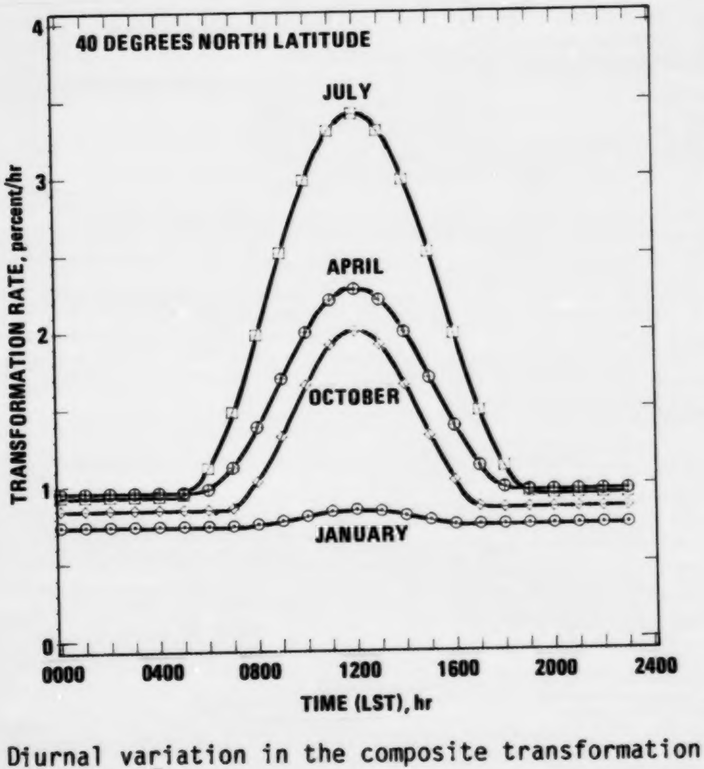


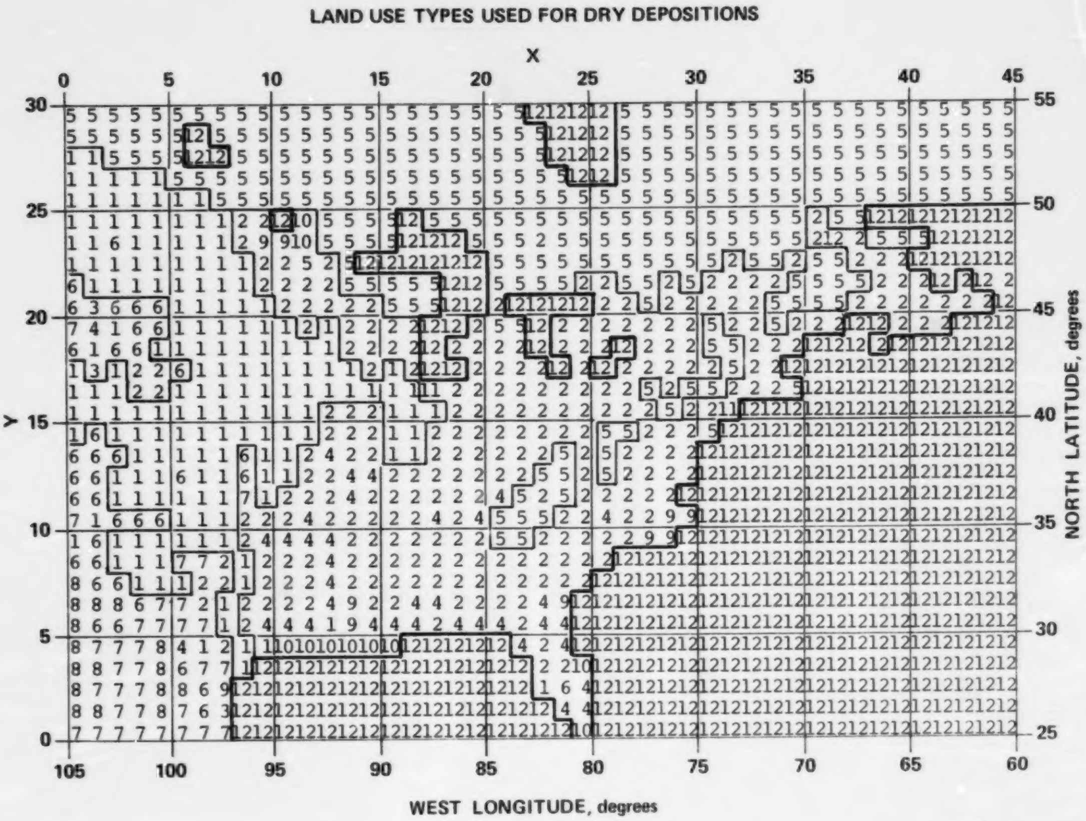
Figure 2.6. Diurnal variation in the composite transformation rate of SO_2 to $SO_4^=$.

DRY DEPOSITION RATES

Dry deposition of SO_2, $SO_4^=$, and fine and coarse particulate matter is a highly variable, complex process that is parameterized by RELMAP as a function of predominant land use, stability index, and season. Twelve land use categories, defined by surface characteristics and vegetation type (Sheih et al., 1979), were gridded to RELMAP's 1° x 1° resolution (default). Figure 2.7 shows the grid of homogeneous land use types and their corresponding surface roughness scale lengths (z_0).

Dry deposition velocities (V_d), which represent the downward surface flux divided by the local concentration, were calculated for each land use type, for six different stability classes and each season for SO_2, $SO_4^=$, and fine and coarse particulate matter. The atmospheric stabilities used to determine the dry deposition velocities are the six Pasquill-Gifford categories: (A) very unstable, (B) moderately unstable, (C) slightly unstable, (D) near neutral, (E) moderately stable, and (F) very stable (Gifford, 1976). The dry deposition velocities, measured in centimeters per second, are used in the model to determine dry deposition rates (in percent of pollutant per hour).

The determination of the dry deposition velocities of SO_2, $SO_4^=$, and fine particulate matter is based on the work of Sheih et al. (1979), as presented below. Dry deposition velocities of coarse particulate matter are based on the work of Sehmel (1980) and are parameterized somewhat differently.


LAND USE TYPES USED FOR DRY DEPOSITIONS
X
0
5
10
15
20
25
30
35
40
45
Y
30
25
20
15
10
5
0
55
50
45
40
35
30
25
NORTH LATITUDE, degrees
105
100
95
90
85
80
75
70
65
60
WEST LONGITUDE, degrees

Symbol	Land Use Type	z_0 (cm)
1	Cropland and Pasture	20
2	Cropland, Woodland, and Grazing	30
3	Irrigated Crops	5
4	Grazed Forest and Woodland	90
5	Ungrazed Forest and Woodland	100
6	Subhumid Grassland and Semiarid Grazing	10
7	Open Woodland, Grazed	20
8	Desert Shrubland	30
9	Swamp	20
10	Marshland	50
11	Metropolitan City	100
12	Lake or Ocean	0.01

Figure 2.7. Land use categories used for dry deposition calculations and corresponding surface roughness lengths (Sheih *et al*., 1979).

SO_2, $SO_4^=$ and Fine Particulate Matter

The RELMAP algorithm for the dry deposition velocity of SO_2, $SO_4^=$, and fine particulate matter is a modified version of the algorithm suggested by Sheih *et al*. (1979):

$$V_d = Ku_* \left(\ln \left(\frac{z}{z_0}\right) + Ku_* r_p - \Psi_c\right)^{-1}, \qquad (2.9)$$

where K is the von Karman constant (0.4), u_* is the friction velocity, z_0 is the surface roughness scale length derived from the 12 land use categories, r_p is the surface resistance to particle deposition (estimated by Sheih *et al*. to be approximately 1.0 s/cm), and Ψ_c is a stability factor.

The calculation of dry deposition velocities for $SO_4^=$ and fine particulate matter differs slightly from (2.9). This is because more recent studies (Wesely and Shannon, 1984) concluded that earlier dry deposition velocities of $SO_4^=$ (based on preliminary micrometeorological field experiments) were too high by a factor of two. To alleviate this overestimation, the $SO_4^=$ and fine particulate dry deposition velocities generated by (2.5) were reduced by half. Table 2.5 shows that dry deposition velocities for SO_2 range between 0.05 and 1.15 cm/s. Table 2.6 shows that velocities for $SO_4^=$ and fine particulate matter range between 0.05 and 0.50 cm/s, depending on stability, season, and land use category.

Use of the deposition velocity tables for stability categories A through F is not always accurate when considering diurnal variations. To compensate for the very high nocturnal atmospheric resistance, when plant absorption is minimal, Sheih *et al*. (1979) recommended that the dry deposition velocities for SO_2, $SO_4^=$, and fine particulate matter be reduced to 0.07 cm/s during the nighttime hours. This nighttime adjustment is reflected in the algorithm used to calculate the dry deposition rate [in percent of initial concentration per user-defined time interval (default = 2 h)] for SO_2, $SO_4^=$, and fine particulate matter:

$$\text{Dry Deposition Rate} = 1.0 - [1.0 - (0.18)(V_d(\%\ \text{DAY}) + .07(\%\ \text{NIGHT}))]^t \qquad (2.10)$$

The constant, 0.18, is a factor used to convert centimeters per second to percent per hour, and the variables, % DAY and % NIGHT (which sum to 1.0), represent the percentage of daytime and nighttime hours in a given time step, respectively.

TABLE 2.5. SEASONAL SO_2 DRY DEPOSITION VELOCITIES (cm/s) BY LAND USE CATEGORY AND P-G STABILITY CLASS

Land Use Category	Winter						Spring					
	A	B	C	D	E	F	A	B	C	D	E	F
Cropland and Pasture	0.30	0.35	0.35	0.15	0.05	0.25	0.65	0.75	0.75	0.35	0.05	0.55
Cropland, Woodland, and Grazing Land	0.30	0.35	0.35	0.15	0.05	0.30	0.65	0.75	0.75	0.35	0.05	0.65
Irrigated Crops	0.20	0.25	0.40	0.15	0.05	0.30	0.45	0.55	0.85	0.35	0.05	0.45
Grazed Forest and Woodland	0.40	0.40	0.40	0.15	0.05	0.40	0.85	0.85	0.85	0.35	0.05	0.85
Ungrazed Forest and Woodland	0.40	0.40	0.40	0.15	0.05	0.40	0.85	0.85	0.85	0.35	0.05	0.85
Subhumid Grassland and Semiarid Grazing Land	0.25	0.30	0.35	0.10	0.05	0.20	0.55	0.65	0.75	0.25	0.05	0.45
Open Woodland, Grazed	0.30	0.35	0.35	0.10	0.05	0.25	0.65	0.75	0.75	0.25	0.05	0.55
Desert Shrubland	0.20	0.20	0.40	0.15	0.05	0.05	0.45	0.45	0.85	0.35	0.05	0.05
Swamp	0.45	0.55	0.35	0.45	0.25	0.25	0.95	1.15	0.75	0.95	0.55	0.55
Marshland	0.45	0.50	0.40	0.15	0.05	0.35	0.95	1.05	0.85	0.35	0.05	0.75
Metropolitan City	0.05	0.05	0.05	0.05	0.05	0.40	0.05	0.05	0.05	0.05	0.05	0.85
Lake or Ocean	0.10	0.15	0.25	0.35	0.15	0.10	0.25	0.35	0.55	0.75	0.35	0.15

Land Use Category	Summer						Fall					
	A	B	C	D	E	F	A	B	C	D	E	F
Cropland and Pasture	0.65	0.75	0.75	0.35	0.05	0.55	0.50	0.55	0.55	0.25	0.05	0.40
Cropland, Woodland, and Grazing Land	0.65	0.75	0.75	0.35	0.05	0.65	0.50	0.55	0.55	0.25	0.05	0.50
Irrigated Crops	0.45	0.55	0.85	0.35	0.05	0.45	0.35	0.40	0.65	0.25	0.05	0.35
Grazed Forest and Woodland	0.85	0.85	0.85	0.35	0.05	0.85	0.65	0.65	0.65	0.25	0.05	0.65
Ungrazed Forest and Woodland	0.85	0.85	0.85	0.35	0.05	0.85	0.65	0.65	0.65	0.25	0.05	0.65
Subhumid Grassland and Semiarid Grazing Land	0.55	0.65	0.75	0.25	0.05	0.45	0.40	0.50	0.55	0.20	0.05	0.35
Open Woodland, Grazed	0.65	0.75	0.75	0.25	0.05	0.55	0.50	0.55	0.55	0.20	0.05	0.40
Desert Shrubland	0.45	0.45	0.85	0.35	0.05	0.05	0.35	0.35	0.65	0.25	0.05	0.05
Swamp	0.95	1.15	0.75	0.95	0.55	0.55	0.70	0.85	0.55	0.70	0.40	0.40
Marshland	0.95	1.05	0.85	0.35	0.05	0.75	0.70	0.80	0.65	0.25	0.05	0.55
Metropolitan City	0.05	0.05	0.05	0.05	0.05	0.85	0.05	0.05	0.05	0.05	0.05	0.65
Lake or Ocean	0.25	0.35	0.55	0.75	0.35	0.15	0.20	0.25	0.40	0.55	0.25	0.10

TABLE 2.6. SEASONAL SO$_4^=$ AND FINE PARTICULATE MATTER DRY DEPOSITION VELOCITIES (cm/s) BY LAND USE CATEGORY AND P-G STABILITY CLASS

Land Use Category	Winter						Spring					
	A	B	C	D	E	F	A	B	C	D	E	F
Cropland and Pasture	0.20	0.20	0.20	0.20	0.20	0.10	0.30	0.35	0.35	0.35	0.25	0.15
Cropland, Woodland, and Grazing Land	0.20	0.20	0.20	0.20	0.20	0.10	0.35	0.35	0.35	0.35	0.30	0.15
Irrigated Crops	0.15	0.20	0.20	0.20	0.15	0.10	0.25	0.30	0.30	0.30	0.20	0.15
Grazed Forest and Woodland	0.25	0.25	0.25	0.25	0.20	0.15	0.40	0.40	0.40	0.40	0.35	0.20
Ungrazed Forest and Woodland	0.25	0.25	0.25	0.25	0.20	0.15	0.40	0.40	0.40	0.40	0.35	0.20
Semihumid Grassland and Semiarid Grazing Land	0.20	0.20	0.20	0.20	0.15	0.10	0.30	0.30	0.35	0.35	0.25	0.15
Open Woodland, Grazed	0.20	0.20	0.20	0.20	0.15	0.10	0.30	0.35	0.35	0.35	0.25	0.15
Desert Shrubland	0.20	0.20	0.20	0.20	0.20	0.10	0.35	0.35	0.35	0.35	0.30	0.15
Swamp	0.20	0.20	0.20	0.20	0.20	0.10	0.30	0.35	0.35	0.35	0.25	0.15
Marshland	0.25	0.25	0.25	0.25	0.20	0.15	0.40	0.40	0.40	0.40	0.30	0.20
Metropolitan City	0.25	0.25	0.25	0.25	0.20	0.15	0.40	0.40	0.40	0.40	0.35	0.20
Lake or Ocean	0.05	0.05	0.10	0.10	0.05	0.05	0.10	0.10	0.15	0.15	0.10	0.10

Land Use Category	Summer						Fall					
	A	B	C	D	E	F	A	B	C	D	E	F
Cropland and Pasture	0.40	0.45	0.45	0.45	0.35	0.20	0.30	0.35	0.35	0.35	0.25	0.15
Cropland, Woodland, and Grazing Land	0.45	0.45	0.45	0.45	0.40	0.20	0.35	0.35	0.35	0.35	0.30	0.15
Irrigated Crops	0.35	0.40	0.40	0.40	0.30	0.20	0.25	0.30	0.30	0.30	0.20	0.15
Grazed Forest and Woodland	0.50	0.50	0.50	0.50	0.45	0.30	0.40	0.40	0.40	0.40	0.35	0.20
Ungrazed Forest and Woodland	0.50	0.50	0.50	0.50	0.45	0.30	0.40	0.40	0.40	0.40	0.35	0.20
Subhumid Grassland and Semiaird Grazing Land	0.40	0.40	0.45	0.45	0.35	0.20	0.30	0.30	0.35	0.35	0.25	0.15
Open Woodland, Grazed	0.40	0.45	0.45	0.45	0.35	0.20	0.30	0.35	0.35	0.35	0.25	0.15
Desert Shrubland	0.45	0.45	0.45	0.45	0.40	0.20	0.35	0.35	0.35	0.35	0.30	0.15
Swamp	0.40	0.45	0.45	0.45	0.35	0.20	0.30	0.35	0.35	0.35	0.25	0.15
Marshland	0.50	0.50	0.50	0.50	0.40	0.30	0.40	0.40	0.40	0.40	0.30	0.20
Metropolitan City	0.50	0.50	0.50	0.50	0.45	0.30	0.40	0.40	0.40	0.40	0.35	0.20
Lake or Ocean	0.10	0.10	0.20	0.20	0.10	0.10	0.10	0.10	0.15	0.15	0.10	0.10

Coarse Particulate Matter

To maintain consistency within the structure of the model, dry deposition of coarse particulate matter is parameterized through an approach similar to that previously described. RELMAP uses the same land use and stability categories and incorporates the work of Sehmel (1980), who presented plots of dry deposition velocities of particulate matter as a function of u_*, z_0, particle density, and diameter. Values of u_* (a function of stability, wind speed, and z_0) were determined from the following equation:

$$u_* = Ku(\ln(\frac{z}{z_0}) - \Psi_m)^{-1}, \tag{2.11}$$

The stability function, Ψ_m, used in (2.11) was determined by using the appropriate relationships between the Monin-Obukhov length (L), surface wind speed (u), and stability class (K), as suggested by Sheih et al. (1979).

Determination of u_* allows the selection of the appropriate Sehmel diagram, from which the dry deposition velocity can be obtained for a given z_0. A particle density of 4.0 g/cm^3 was assumed, based on the densities assumed by Mamane and Noll (1985) from their rural particle characterization analyses. Sehmel's study was limited to $z_0 \leq 10$ cm, but most of the land use categories used by the model have z_0 values exceeding 10 cm. Thus, the appropriate dry deposition velocity was extrapolated.

Because coarse particulate matter consists of a wide range of particle diameters, two sets of dry deposition velocities (Table 2.7) were calculated by the previously described methodology. The first set applies to coarse particulate matter with diameters of 5 μm, and the second set applies to particles with diameters of 10 μ m. The user has the option of using either set or a set obtained by averaging the rates in each set. As shown in Table 2.7, dry deposition velocities in RELMAP range between 0.4 to 5.0 cm/s for particles with diameters of 5 μm and between 1.0 to 6.0 cm/s for 10 μ m-diameters.

Unlike SO_2, $SO_4^=$, and fine particulate matter, the dry deposition velocities of coarse particulate matter are much less dependent on the time of day and the season; therefore, diurnal and seasonal variations were considered to be negligible.

After RELMAP determines the appropriate dry deposition velocity for each land use category and stability class, the values are used to calculate the dry deposition rate for coarse particulate matter (in percent of initial concentration per time step) with the following algorithm:

$$\text{Dry Deposition Rate} = 1.0 - [1.0 - (0.18)V_d]^t \qquad (2.12)$$

TABLE 2.7 COARSE PARTICULATE MATTER DRY DEPOSITION VELOCITIES (cm/s) BY LAND USE CATEGORY AND P-G STABILITY CLASS

Land Use Category	5 μ						10 μ					
	A	B	C	D	E	F	A	B	C	D	E	F
Cropland and Pasture	0.6	0.6	0.6	0.6	0.5	0.5	1.0	1.0	1.0	1.0	1.0	1.0
Cropland, Woodland, and Grazing Land	0.6	0.6	0.6	0.6	0.5	0.5	1.0	1.0	1.0	1.0	1.0	1.0
Irrigated Crops	0.6	0.6	0.6	0.6	0.5	0.5	1.0	1.0	1.0	1.0	1.0	1.0
Grazed Forest and Woodland	5.0	5.0	5.0	5.0	0.5	0.5	6.0	6.0	6.0	6.0	1.0	1.0
Ungrazed Forest and Woodland	5.0	5.0	5.0	5.0	0.5	0.5	6.0	6.0	6.0	6.0	1.0	1.0
Semihumid Grassland and Semiarid Grazing Land	0.6	0.6	0.6	0.6	0.5	0.5	1.0	1.0	1.0	1.0	1.0	1.0
Open Woodland, Grazed	0.6	0.6	0.6	0.6	0.5	0.5	1.0	1.0	1.0	1.0	1.0	1.0
Desert Shrubland	0.6	0.6	0.6	0.6	0.5	0.5	1.0	1.0	1.0	1.0	1.0	1.0
Swamp	0.6	0.6	0.6	0.6	0.5	0.5	1.0	1.0	1.0	1.0	1.0	1.0
Marshland	0.6	0.6	0.6	1.0	0.5	0.5	1.0	1.0	1.0	1.0	1.0	1.0
Metropolitan City	5.0	5.0	5.0	5.0	0.5	0.5	6.0	6.0	6.0	6.0	1.0	1.0
Lake or Ocean	0.4	0.4	0.4	0.4	0.4	0.4	1.0	1.0	1.0	1.0	1.0	1.0

WET DEPOSITION RATES

The complex process of wet deposition of SO_2, $SO_4^=$, and fine and coarse particulate matter is thought to be a function of cloud chemistry and cloud type, pollutant concentration, and precipitation type and rate. RELMAP, however, parameterizes wet deposition quite simply, treating it as a function of season and precipitation rate only.

The wet deposition rates are expressed as percentages per time step, and are based on the work of Scott (1978). He presented graphs of washout ratios of $SO_4^=$ concentration in precipitation to $SO_4^=$ concentration in air. These ratios depend solely on precipitation rate and cloud type; the three cloud types considered were Bergeron or cold-type clouds, warm or maritime-type clouds, and convective-type clouds. RELMAP assumes that all winter precipitation results from the Bergeron process, that spring and fall precipitation result from warm cloud formation, and that summer precipitation is confined to convective-type clouds. The algorithm derived from Scott's work has been expanded to incorporate the wet deposition rate (in percent of initial concentration per time step) of SO_2 (SRI, 1982):

$$\text{Wet Deposition Rate} = 1.0 - (1.0 - aR^b)^t, \qquad (2.13)$$

where a and b are seasonal empirical constants derived from the inherent relationship between the washout ratio and the precipitation rate (R).

Because little is known about the wet removal processes of nonsulfate aerosols from the boundary layer, RELMAP assumes identical deposition rates for $SO_4^=$ and fine and coarse particles. This simplistic approach to the wet removal processes of nonsulfate particles will be replaced in the future with more sophisticated parameterizations as further research is undertaken. For now, the constants a and b in (2.13) may be changed by the user.

Wet deposition rates calculated for each season, for a constant precipitation rate of 5 mm/h for a 3-h simulation period are presented in Table 2.8.

TABLE 2.8. WET DEPOSITION RATES FOR SO_2, $SO_4^=$, and FINE AND COARSE PARTICULATE MATTER

Pollutant	Season	Empirical Constants		Wet Deposition Rate (%/3h)
		a	b	
SO_2	Summer	0.140	0.12	0.4278
	Fall/Spring	0.036	0.53	0.2327
	Winter	0.009	0.70	0.0811
$SO_4^=$, and Fine and Coarse Particulate Matter	Summer	0.390	0.06	0.8143
	Fall/Spring	0.091	0.27	0.3650
	Winter	0.021	0.70	0.1821

SECTION 3

MODEL PERFORMANCE EVALUATION

In general, a rigorous evaluation of any model requires a long-term reliable data set consisting of measurements of all parameters simulated by the model across a network of representative sites similar to the spatial and temporal resolution of the model. Unfortunately, a complete data set is not available to rigorously evaluate all aspects of RELMAP. A temporally and spatially consistent data base for ambient concentrations of SO_2, $SO_4^=$, and fine and coarse particulate matter does not exist for 1980, the latest year when emissions data were available. For this year, daily ambient concentrations of SO_2 are available at hundreds of Storage and Retrieval of Aerometric Data (SAROAD) sites, but nearly all of these sites, located in urban areas or near significant sources, are not regionally representative (EPA, 1978).

Also for this year, daily average ambient concentrations of $SO_4^=$ and fine and coarse particulate matter were measured only every sixth day, for at least 12 days in any one season, at fewer than 15 sites across the United States (Hinton _et al_., 1984). Moreover, most of these sites are biased toward local sources, because the network was designed primarily to characterize urban-scale concentrations of suspended particulate matter (Watson _et al_., 1981).

However, a spatially and temporally consistent sulfur wet deposition data base is available to evaluate the model. Such a data set was acquired from the Acid Deposition System (ADS), operated for EPA by Pacific Northwest Laboratory (Watson and Olsen, 1984). The data were screened for completeness and regional representativeness by using criteria established by Voldner _et al_. (1984). This section briefly describes a comparison of a RELMAP simulation to this data base. The results of a more rigorous evaluation will be discussed in the final report of the International Sulfur Deposition Model Evaluation. Monthly simulations of concentrations and wet and dry depositions of SO_2, $SO_4^=$, and total sulfur were made for all of 1980. Emissions data used in the simulation were from the 1980 National Acid Precipitation Assessment Program (NAPAP) Task Group B emissions inventory (Version 2.0) and from the Environment Canada emissions inventory used in Phase III of the U.S.-Canadian Memorandum of Intent on Transboundary Air Pollution (Clark _et_ _al_., 1985).

Seasonal and annual predictions of sulfur wet deposition (expressed in kilograms of $SO_4^=$ per hectare) were compared to the amount of seasonal and annual sulfur wet deposition recorded by the ADS system. The number of observations for the seasonal evaluations ranged from 36 in winter (January-March) to 43 in spring (April-June) and summer (July-September). Autumn (October-December) had 41 observations, and the statistics for the annual evaluation were limited to the 34 stations that had observations for all four seasons.

The means and standard deviations of the observed, predicted, and residual (observed - predicted) values of total sulfur wet deposition were calculated for each of the sites (Table 3.1). The minimum and maximum values and Pearson's product-moment correlation coefficient are also in Table 3.1.

Comparison of the means and standard deviations of the predicted and observed values, with their corresponding residuals, provides an indication of the model's performance. Table 3.1 shows that the model slightly overpredicted total sulfur wet deposition during the winter (0.01 kg-$SO_4^=$/ha, or 0.22%). It overpredicted wet deposition during the spring (2.02 kg-$SO_4^=$/ha, or 25.73%) and summer (3.43 kg-$SO_4^=$/ha, or 37.12%). It underpredicted for autumn (0.37 kg-$SO_4^{=}$/ha or 9.23%). In the annual simulation, the model again overpredicted total sulfur wet deposition (5.41 kg-$SO_4^{=}$/ha, or 20.66%). The percentages of over/underprediction were calculated by dividing the residuals by the mean of total observed sulfur wet deposition, by season. Much of the overprediction found in the model simulations can be attributed to a few sites located within the heart of the industrial region.

TABLE 3.1. STATISTICAL EVALUATION OF RELMAP*

Season	Mean Obs.	Mean Pred.	Std. Dev. Obs.	Std. Dev. Pred.	Bias (O-P)	Std. Dev. Resid.	Minimum Obs.	Minimum Pred.	Maximum Obs.	Maximum Pred.	Corr.
Winter (n=36)	4.41	4.42	2.06	2.73	-0.01	2.51	0.80	0.10	9.60	10.62	0.479
Spring (n=43)	7.85	9.87	2.96	7.20	-2.02	5.59	2.20	0.48	15.80	37.56	0.689
Summer (n=43)	9.24	12.67	5.12	10.61	-3.43	8.81	0.90	0.09	23.60	53.37	0.562
Autumn (n=41)	4.07	3.70	1.85	1.95	0.37	2.40	0.90	0.06	9.50	8.40	0.208
Annual (n=34)	26.19	31.60	10.34	22.15	-5.41	17.79	6.15	0.78	47.30	109.98	0.614

* Units are kilograms of $SO_4^{=}$ per hectare.

Scatter diagrams (Figures 3.1-3.3), which exhibit the correlation or dependency of the predicted values on the observed values, reveal that the model produced higher correlations during spring and summer than it did during autumn and winter. The annual simulation produced a Pearson's correlation coefficient of 0.614, which indicates that 37.7% of the variance exhibited by the observed data can be accounted for by the simulation.

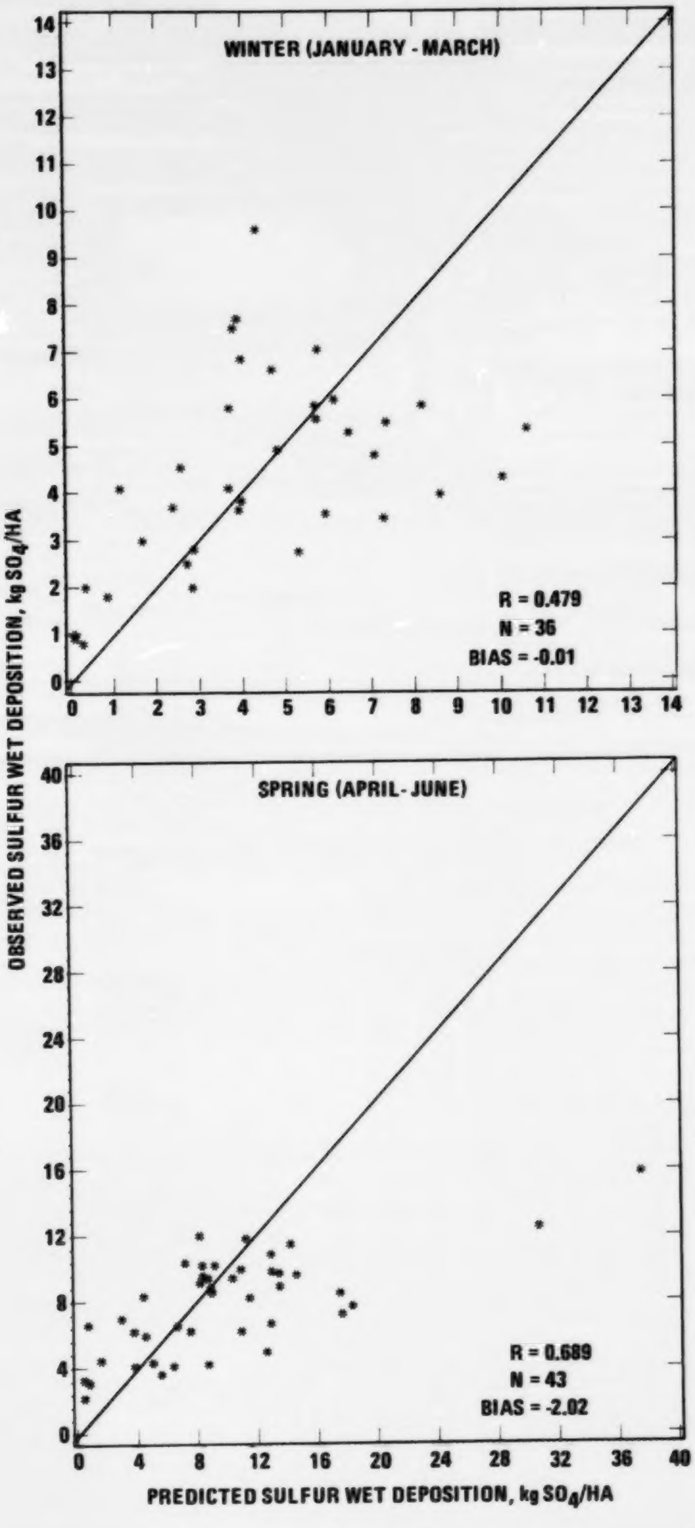


Figure 3.1. Scatter diagrams of predicted vs. observed values of sulfur wet deposition for winter and spring of 1980 (1:1 ratio reference line).

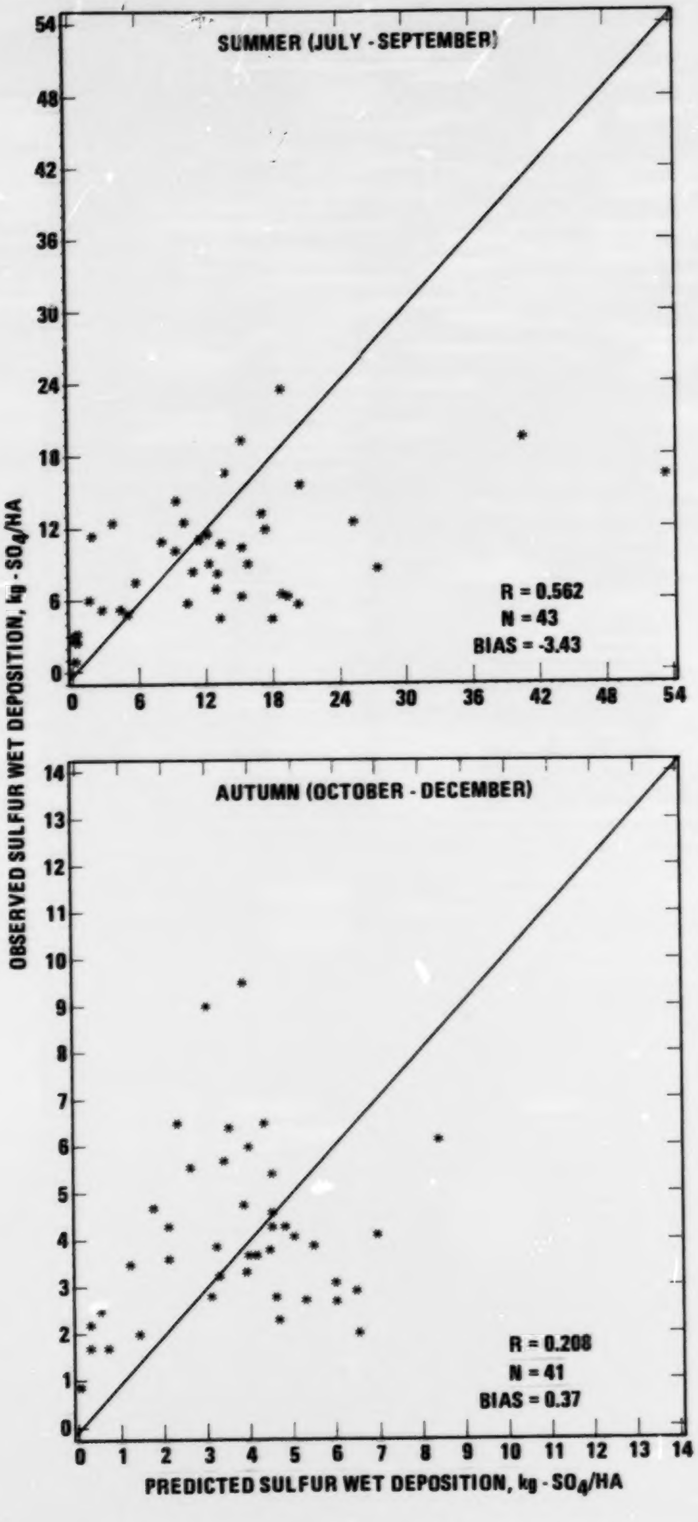


Figure 3.2. Scatter diagrams of predicted vs. observed values of sulfur wet deposition for summer and autumn of 1980 (1:1 ratio reference line).

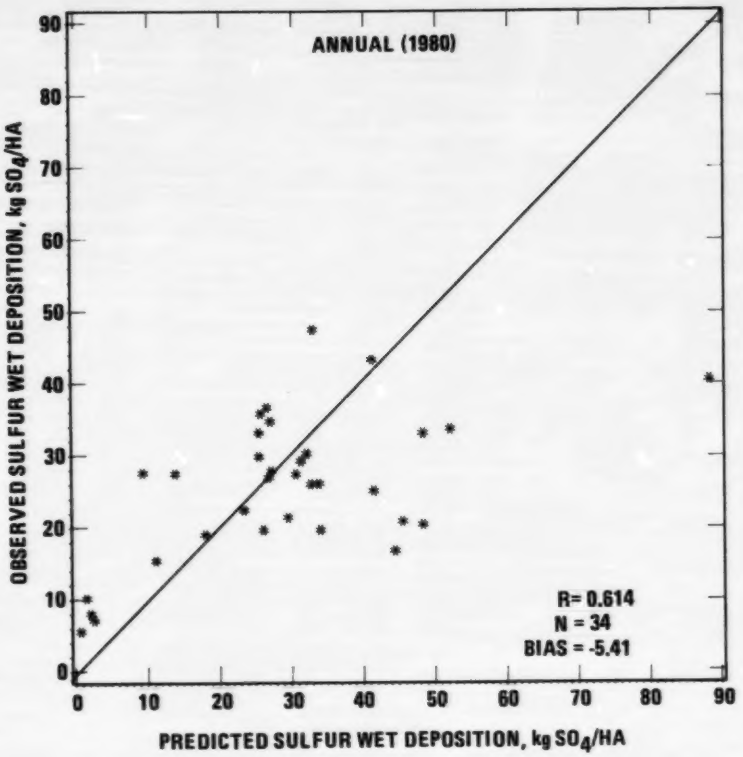


Figure 3.3. Scatter diagram of predicted vs. observed values of sulfur wet deposition for all of 1980 (1:1 ratio reference line).

The overpredictions of the model simulation are illustrated by the standardized residuals [(observed - predicted)/observed] for each of the evaluation sites (as shown in Figures 3.4 and 3.5 for the seasons and in Figure 3.6 for the year). There is a consistent tendency within each season for the model to overpredict total sulfur wet deposition in the major source regions (i.e., Ohio River Valley) and to underpredict wet deposition in the nonindustrial regions.

The pronounced overprediction that occurs in spring and summer can in part be attributed to two factors: (1) the model does not account for sub-grid-scale precipitation variability, and (2) the model does not

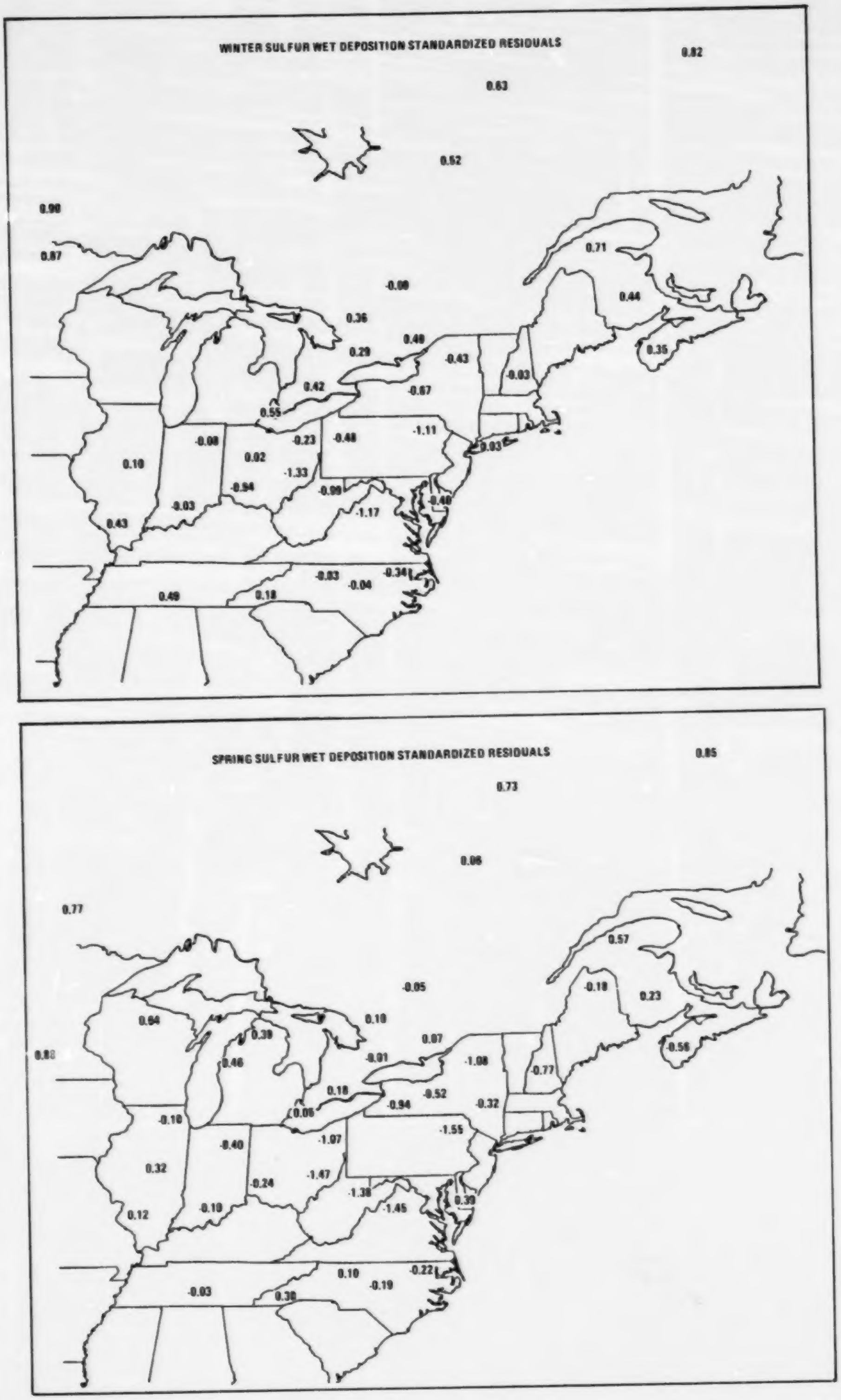

WINTER SULFUR WET DEPOSITION STANDARDIZED RESIDUALS
0.82
0.63
0.52
0.90
0.87
0.71
-0.09
0.44
0.36
0.40
0.29
-0.43
0.35
-0.03
0.42
-0.67
0.55
-1.11
-0.08
0.02
-0.23
-0.48
0.03
0.10
-1.33
-0.94
-0.09
-0.40
-0.03
-1.17
0.43
-0.83
-0.04
-0.34
0.49
0.18
SPRING SULFUR WET DEPOSITION STANDARDIZED RESIDUALS
0.85
0.73
0.06
0.77
0.57
-0.05
-0.10
0.23
0.94
0.10
0.39
0.07
0.88
-0.01
-1.08
-0.56
0.46
-0.77
0.18
-0.94
-0.52
-0.32
0.06
-0.10
-1.55
-0.40
-1.07
0.32
-1.47
-0.24
-1.38
0.39
-1.45
0.12
-0.10
0.10
-0.19
-0.22
-0.03
0.30

Figure 3.4. Sulfur wet deposition standardized residuals for winter and spring of 1980.

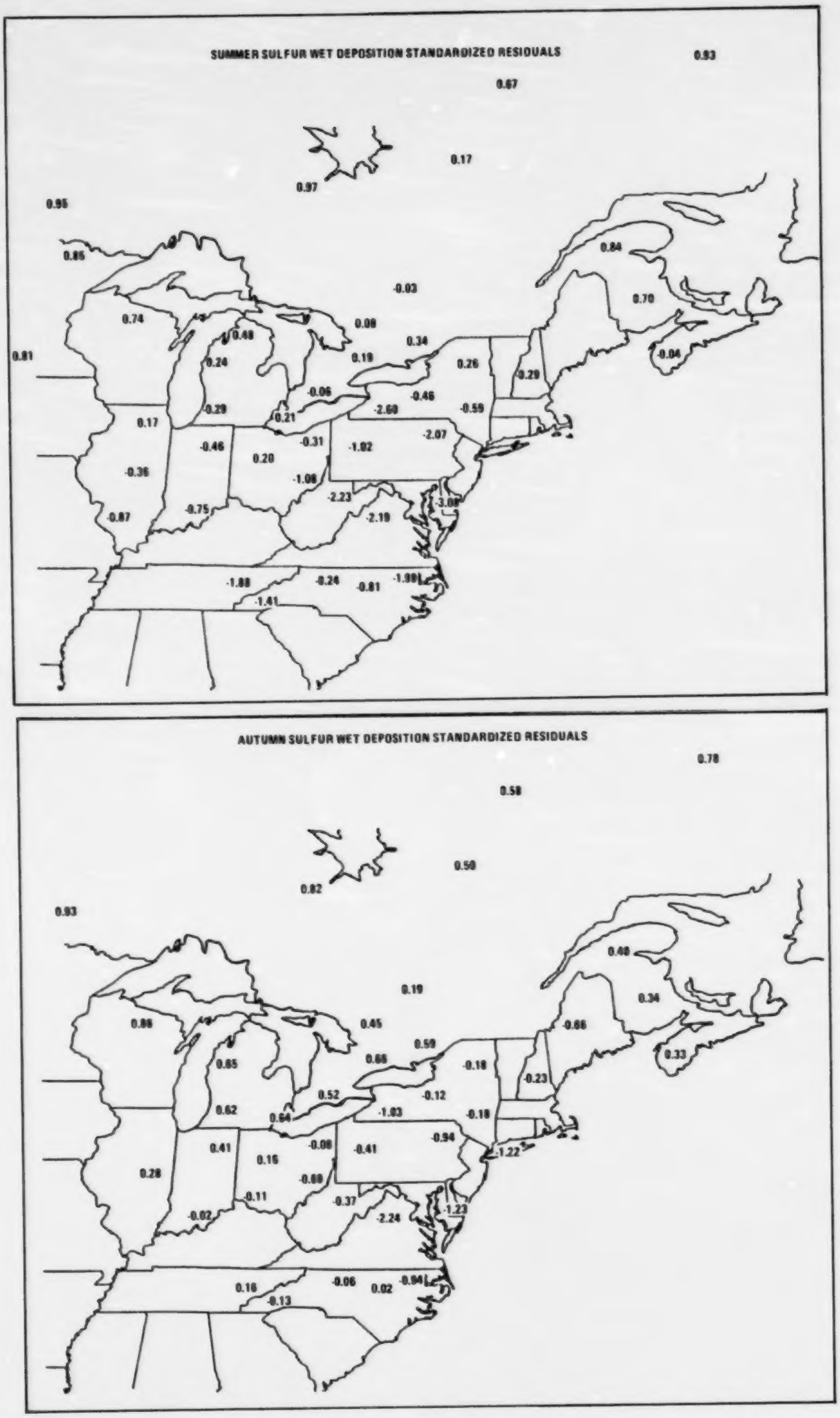

SUMMER SULFUR WET DEPOSITION STANDARDIZED RESIDUALS
0.93
0.67
0.17
0.97
0.95
0.85
0.84
-0.03
0.70
0.74
0.08
0.48
0.34
0.81
0.24
0.19
0.26
-0.04
-0.29
-0.06
-0.46
-0.29
-2.60
-0.59
0.21
0.17
-0.46
-0.31
-2.07
-1.02
0.20
-0.36
-1.08
-2.23
-3.08
-0.87
-0.75
-2.19
-1.88
-0.24
-0.81
-1.98
-1.41
AUTUMN SULFUR WET DEPOSITION STANDARDIZED RESIDUALS
0.78
0.58
0.50
0.82
0.93
0.48
0.19
0.34
0.86
0.45
-0.66
0.59
0.66
0.33
0.85
-0.18
-0.23
0.52
-0.12
0.62
-1.03
-0.18
0.64
-0.94
0.41
-0.08
-0.41
-1.22
0.16
0.28
-0.08
-0.11
-0.37
-1.23
-0.02
-2.24
0.16
-0.06
0.02
-0.94
-0.13

Figure 3.5. Sulfur wet deposition standardized residuals for summer and autumn of 1980.

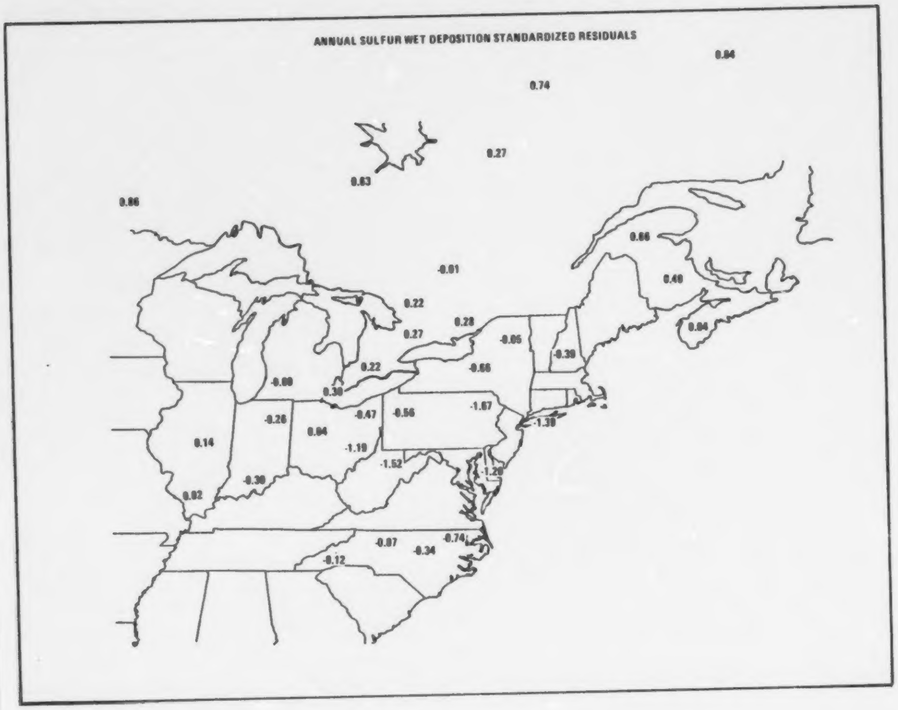

ANNUAL SULFUR WET DEPOSITION STANDARDIZED RESIDUALS
0.84
0.74
0.27
0.83
0.86
0.86
-0.01
0.40
0.22
0.28
0.04
0.27
-0.05
-0.39
-0.66
0.22
-0.80
0.38
-1.67
-0.26
-0.47
-0.56
-1.38
0.04
0.14
-1.19
-1.52
-1.28
-0.30
0.02
-0.74
-0.87
-0.34
-0.12

Figure 3.6. Sulfur wet deposition standardized residuals for all of 1980.

account for the vertical transport of pollutants from the mixed layer into the free troposphere by cumulus cloud venting. RELMAP assumes that precipitation occurs everywhere within a grid cell whenever precipitation occurs at any site within that cell. Therefore, the frequency of simulated precipitation events in any grid cell is higher than the actual frequency at one site in that cell, particularly during the months of convective activity (spring and summer). Consequently, wet deposition will occur more frequently in the simulations.

In support of the second factor attributed to model overprediction, Isaac _et al_. (1983) estimated that clouds vent 20% of the subcloud layer air into the free troposphere during the winter and 50% in the summer. Also, Liu _et al_. (1984) estimated that 55% of Radon 222 originating from the ground was transported out of the mixed layer by cumulus cloud venting during the summer. Failure to account for such vertical transport could result in excessive sulfur wet deposition near the source regions, especially during the convective seasons (spring and summer), which is consistent with this analysis.

SECTION 4

COMPUTER ASPECTS

INTRODUCTION

This section describes the input data and file formats required to process data through the series of programs that comprise the RELMAP system. We assume here that the user has successfully loaded, compiled, and mapped (or linked) the programs and their respective subroutines. A table of programs with the subroutines they call is provided in Appendix A to assist the user in this process.

The system consists of two parts: preprocessors, and the model itself. In its most complex form, the model requires five types of preprocessed input data. Four types of data must be supplied by the user: upper air data, surface observation data, precipitation data, and emissions data. These data can be obtained from several sources. Table 4.1 contains a list of addresses of sources from which these data may be obtained. Dry deposition velocities, contained in a preprocessor program called DEPPUFP, are the fifth type of data required by the model. Data requirements for the preprocessors are described in detail later in this section.

Some of the preprocessors consist of a sequence of programs. In these sequences, the output file format of one program is the input file format for the next program in the sequence. Therefore, once the user has formatted the first file in the sequence, he does not have to format the remainder of the files, because their formats are identical. Consequently, this section only provides the information necessary to execute the preprocessors from the beginning of the sequence. Output file format specifications for some programs are listed in tabular form in Appendix B. Error messages are listed in Appendix C.

TABLE 4.1. RELMAP DATA SOURCES

Data Type	Source
U.S. Emissions	National Air Data Branch, MD-14 Office of Air Quality Planning & Standards U.S. Environmental Protection Agency Research Triangle Park, NC 27711 (FTS) 629-5582 (919) 541-5582
or	
	Environmental Monitoring Systems Laboratory Office of Research and Development, MD-61 U.S. Environmental Protection Agency Research Triangle Park, NC 27711 (FTS) 629-2612 (919) 541-2612
Canadian Emissions	Data Analysis Division Air Pollution Control Directorate Environment Canada Ottawa, Ontario K7A 7C8 (819) 994-3127
Meteorological Data	National Center for Atmospheric Research Data Support Section P.O. Box 3000 Boulder, CO 80307 (FTS) 320-1216 (303) 497-1216
or	
	National Climatic Data Center Federal Building Asheville, NC 28801 (FTS) 672-0683 (704) 259-0683

System-Dependent Limitations

The software for the RELMAP model and preprocessors is written in ASCII FORTRAN and was developed and tested on the Sperry UNIVAC 1100/82 at the National Computer Center at the U.S. Environmental Protection Agency's site in Research Triangle Park, North Carolina. Three UNIVAC-specific routines are used in the software: ADATE, SORT, and ATAPE. If the user has a different computer system, he must substitute routines from his system.

ADATE is a UNIVAC routine that returns the present date and time to the user whenever it is called. It is used by the preprocessors to supply a creation date and time for the file headers. The deletion of this routine will not prevent the programs from running.

SORT is a UNIVAC sorting routine. It is used twice in the preprocessors of precipitation data (once for U.S. data and once for Canadian data) to sort data into chronological files by date and time.

ATAPE is a magnetic tape handler that is used to read data tapes by the following programs in the preprocessors: PGM-RAOB, PGM-SFC1, LOCATR, MASTER, RTREV, C-LOCAT, CANRAIN, PACK-POINT, and PACK-AREA.

ATAPE was written by the personnel at the Atmospheric Sciences Research Laboratory of the U.S. Environmental Protection Agency for use on the Sperry UNIVAC. It is an assembly language routine. The version on the UNIVAC is a multifunctional routine capable of reading from and writing to magnetic tapes, rewinding tapes, writing EOF's to tape files, and moving tapes forward and backward. ATAPE reads one physical record from the tape, beginning with the first record, and transfers it to an array. ATAPE is not limited to reading a particular blocking structure, because it reads one physical record; therefore, it is capable of reading fixed-length and variable-length blocks. The program from which ATAPE is called decodes the array and retrieves the logical records from the physical records.

The routine included with this version of RELMAP consists only of a discussion of the arguments and functions of ATAPE. The comments in the code include the assembly language code, in case the user implements the RELMAP system on a UNIVAC 1100 series machine. In RELMAP, the internal file name for all input tapes read with ATAPE is TAPEA.

There are no current standard ASCII FORTRAN equivalents for ATAPE when it is used to read a tape. The user will have to develop his own routine to read the magnetic tapes, or use a system routine (for example, NTRAN$ on the UNIVAC, BUFFERIN on a CYBER, RECFORM=U on the IBM) from his computer facility, if one is available.

Other Considerations

Grid Size/PARAMETER Statements

To change the size and/or location of the domain, the user must change the appropriate PARAMETER statement in all the programs in which the statement appears. Appendix D contains lists of variables in the code that must be changed for all programs with PARAMETER statements. The following programs include this PARAMETER statement:

- PGM-RAOB
- PGM-RAOB2
- PGM-SFC1
- PGM-SFC2
- PGM-TIME
- CANRAIN
- RTREV
- GRID
- HOLEZ (also subroutines BARNES & GRIDZ)
- RELMAPP
- RELMAPA
- DEPPUFP
- WNDO-FIL
- All subroutines in the RELMAP model itself, except PRORAT

OPEN Statements

Some programs in the preprocessor and subroutines in the model itself use an OPEN statement to assign files. The user should be aware that these statements sometimes cause difficulties when moved to other computer systems.

NAMELIST

The NAMELIST statement defines a list of variable or array names and associates the list with a group name. In lieu of an input/output list, the group name is used in a NAMELIST-directed input/output statement to define the variables or arrays that are to be read or written. The form of the NAMELIST is as follows:

```
NAMELIST/group name/list of variable or array names
```

The form of the output statement is as follows:

```
WRITE ([UNIT= ] unit number, [NML= ] group name)
```

The brackets indicate optional key words.

In an input statement, READ replaces WRITE. The file that is read must be structured according to the requirements of the computer system. On the UNIVAC, the first line must be as follows: $group name. The first line must begin in column 2. The variable names and values follow in any order and have the following form: variable name = value,. The comma is required after each assignment except the last one. The final line of the file is as follows: $END. This line must begin in column 1.

The user should consult his system user's guide to determine the applicability of these statements. If the programs do not compile because of the presence of NAMELIST-directed input/output, the user should restructure the READ and WRITE statements to conform to ASCII FORTRAN standards, with input and output lists and FORMAT statements.

Model Constraints

The user should remember that the model will run a maximum of one month of data at a time. He should also remember that the two output formats (source-receptor or gridded arrays) are mutually exclusive. In other words, the model must be run twice if the user wants both output formats.

PREPROCESSORS

RELMAP requires five types of input data to run the model in its most complex form. These five data types (upper air data, surface observation data, precipitation data, emissions data, and dry deposition velocities for SO_2, $SO_4^=$, and fine and coarse particulate matter) are prepared by preprocessor programs for use by the RELMAP model (Figure 4.1). The first four types of data must be supplied by the user. Dry deposition velocities are calculated by a preprocessor program (DEPPUFP); the user does not have to supply any raw data for this program, although he can change the values of the factors used in the equations that calculate the velocities. These equations are described in Section 2. Additionally, if the user has chosen the source-receptor output mode (see description in Section 1), he must use another preprocessor program (WINDO-FIL) to prepare a special data file required for this mode. In the following discussions, logical unit assignments are given when more than the UNIVAC default input unit (5) and output unit (6) are required. Each of the preprocessors is described briefly; emphasis is on providing the user with the necessary information for executing the programs.

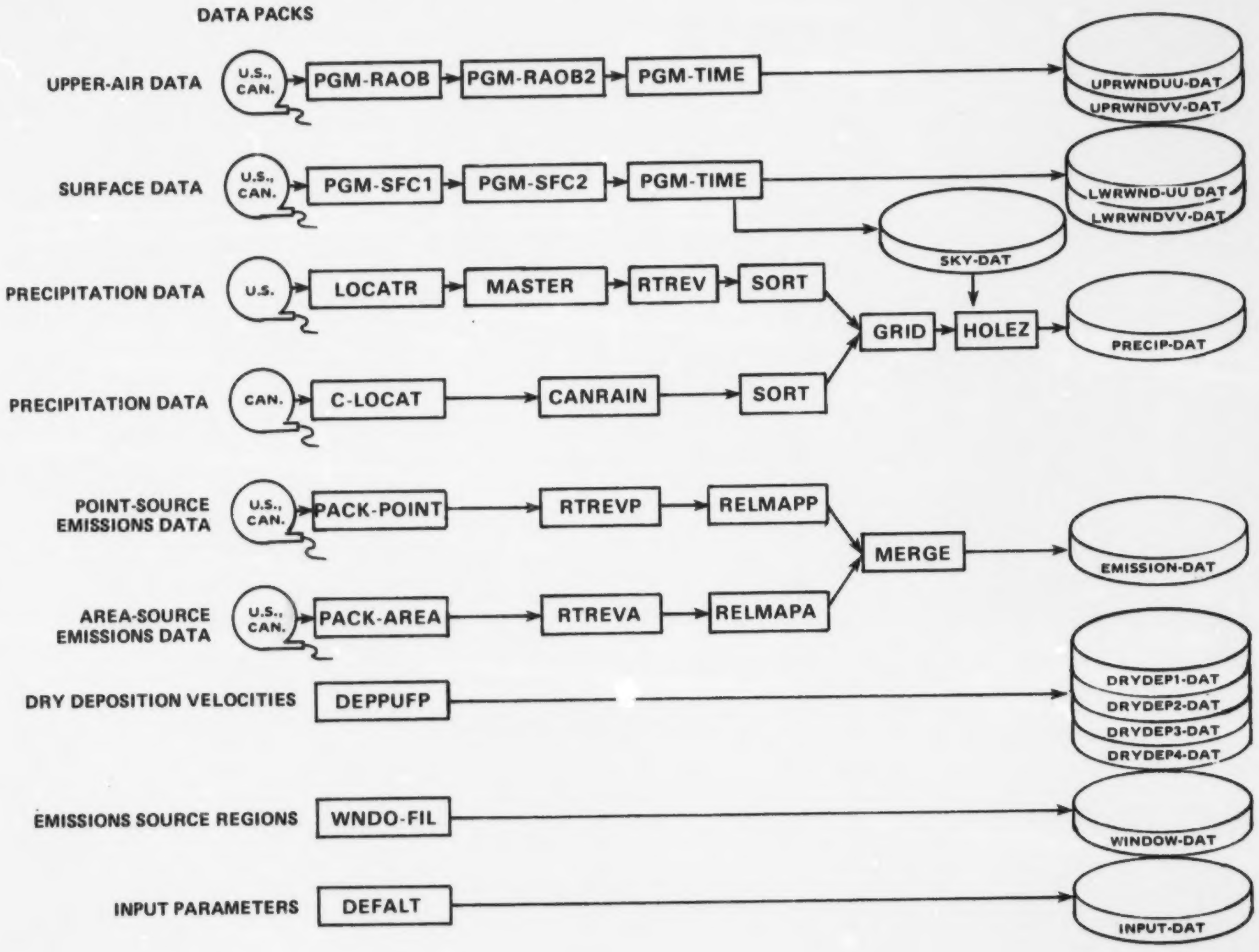

DATA PACKS
UPPER-AIR DATA
U.S., CAN.
PGM-RAOB
PGM-RAOB2
PGM-TIME
UPRWNDUU-DAT
UPRWNDVV-DAT
SURFACE DATA
U.S., CAN.
PGM-SFC1
PGM-SFC2
PGM-TIME
LWRWND-UU DAT
LWRWNDVV-DAT
SKY-DAT
PRECIPITATION DATA
U.S.
LOCATR
MASTER
RTREV
SORT
GRID
HOLEZ
PRECIP-DAT
PRECIPITATION DATA
CAN.
C-LOCAT
CANRAIN
SORT
POINT-SOURCE EMISSIONS DATA
U.S., CAN.
PACK-POINT
RTREVP
RELMAPP
MERGE
EMISSION-DAT
AREA-SOURCE EMISSIONS DATA
U.S., CAN.
PACK-AREA
RTREVA
RELMAPA
DRY DEPOSITION VELOCITIES
DEPPUFP
DRYDEP1-DAT
DRYDEP2-DAT
DRYDEP3-DAT
DRYDEP4-DAT
EMISSIONS SOURCE REGIONS
WNDO-FIL
WINDOW-DAT
INPUT PARAMETERS
DEFALT
INPUT-DAT

Figure 4.1. Structure diagram of preprocessors used for RELMAP.

Surface Observation Data

Two programs (PGM-SFC1 and PGM-SFC2) are used to extract and grid surface wind and cloud coverage data from meteorological tapes (in 6-h increments) obtained from the National Center for Atmospheric Research (NCAR) for the United States and Canada. These preprocessor programs accommodate the format of the NCAR tapes. The user may substitute tapes from the National Climatic Data Center (NCDC), but he will have to rewrite the programs to accommodate the NCDC data. Tables B.1 and B.2, in Appendix B, describe the output formats of the data in PGM-SFC1. NCAR and NCDC both provide documentation on tape formats with requested data tapes. The data from these two programs are adjusted to the user-specified time step by PGM-TIME. The final products of the preprocessed surface data are two files called LWRWNDUU and LWRWNDVV, which are used as input files to the RELMAP model.

PGM-SFC1

This program extracts surface wind and cloud coverage data from NCAR data tapes (in 6-h increments) and produces two output files. The first file (SFCWEA) is in ASCII character format (logical unit 10) and contains the station ID, date, location, temperature, dew point, wind direction and speed, sky condition, and time of observation. The user can print out and visually scan this file for errors. The second file (SFCRAIN) is written in binary (unformatted) and assigned to logical unit 11. It contains the date, station ID, location, and precipitation data. The second file also contains supplemental data not found in the formatted file: mixing height, and stability categories. Table 4.2 is the input card image for this program.

TABLE 4.2. INPUT CARD IMAGE FOR PGM-SFC1

Record Type	Number of Records	Variable	Description	Units	Format/Type*
1	1	JMO	Starting month (01-12)	--	I
		JYR	Starting year (last 2 digits of the year)	--	I
		JDA	Starting day (of month JMO)	--	I
		KMO	Ending month (01-12)	--	I
		KDA	Ending day (of month KMO)	--	I

* Free format.

PGM-SFC2

This program calculates the u- and v-components of the surface wind data extracted by PGM-SFC1. It then grids these values and the cloud coverage data in two steps: (1) values are generated at every third grid cell in the north-south and east-west directions by using the Barnes (1973) method; (2) with the $1/R^2$ rule, intervening grid cells are evaluated by using the value of the grid cell closest to the intervening grid cell being evaluated. It also grids mixing height and stability category data. Files are assigned to the following logical unit numbers: 8 = ASCII input from PGM-SFC1; 9 = binary input from PGM-SFC1; 11 = output, gridded surface wind u-components (in meters per second); 12 = output, gridded surface wind v-components (in meters per second); 13 = output, gridded cloud coverage data (in percent of sky covered). Other files that are generated include 10 (ungridded precipitation data, in inches), 14 (gridded stability categories), and 15 (gridded mixing heights, in meters). These files may be used by setting the appropriate logical options to .TRUE. in the subroutine DEFALT in the RELMAP model. Table 4.3 contains the required internal file names of the output files.

TABLE 4.3. REQUIRED INTERNAL FILE NAMES FOR PGM-SFC2

File Name	Unit Number	Description
SSFCU	11	Gridded u-components
SSFCV	12	Gridded v-components
SSKYE	13	Gridded cloud coverage data
SRAIN	10	Ungridded precipitation data
SSTAB	14	Gridded stability categories
SMIXH	15	Gridded mixing heights

Table 4.4 is the input card image for PGM-SFC2. The names the user assigns to the output files listed in the input card image will appear in the header of the printout. The names may be the same as their equivalent internal file names, or they may be different, perhaps a short header describing their contents (e.g., UWINDCOMP).

TABLE 4.4. INPUT CARD IMAGE FOR PGM-SFC2

Record Type	Number of Records	Variable	Description	Units	Format/Type
1	1	FH(1)	Name assigned to file 10 (Precipitation data file)	--	A28
2	1	FH(2)	Name assigned to file 11 (Gridded u-component of surface winds)	--	A28
3	1	FH(3)	Name assigned to file 12 (all gridded v-components of surface winds)	--	A28
4	1	FH(4)	Name assigned to file 13	--	A28
5	1	FH(5)	Name assigned to file 14	--	A28
6	1	FH(6)	Name assigned to file 15	--	A28
7*	1	JMO	Starting month number	--	I
	1	JYR	Starting year (last 2 digits of the year)	--	I
	1	JDA	Starting day of month (JMO)	--	I

* Record 7 is in free format

Upper Air Data

Two programs (PGM-RAOB and PGM-RAOB2) are used to extract and grid 12-h 850-mb and surface wind data from meteorological tapes obtained from NCAR for the United States and Canada. These preprocessor programs are formatted to accomodate the format of the NCAR tapes. The user may substitute tapes from NCDC, but he will have to rewrite the programs to accept the data. Tables B.3 and B.4, in Appendix B, describe the output formats used in PGM-RAOB. With requested data tapes, NCAR provides documentation describing tape formats. NCDC also provides format documentation with its tapes. The data from these two programs are adjusted to the user-specified time step by PGM-TIME. The final product of the preprocessed upper air data are two files with the required names of UPRWNDUU-DAT and UPRWNDVV-DAT. These are input files to the RELMAP model.

PGM-RAOB

This program extracts 850-mb and surface winds from NCAR data tapes and produces two output files. The first is a formatted file called TSAVE (logical unit 10), which the user can print out and visually scan for errors. The second file (WSAVE) is written in binary (logical unit 11) and is used as input for PGM-RAOB2. It contains date and time, location, height, and wind speed and direction. PGM-RAOB also computes mixing heights (defined as the lifting condensation level). Table 4.5 is the input card image for this program (free format).

TABLE 4.5. INPUT CARD IMAGE FOR PGM-RAOB

Record Type	Number of Records	Variable	Description	Units	Format/Type*
1	1	JMO	Starting month (01-12)	--	I
		JYR	Starting year (last 2 digits of the year)	--	I
		JDA	Starting day (of month JMO)	--	I
		KMO	Ending month (01-12)	--	I
		KDA	Ending day (of month KMO)	--	I

* Free format.

PGM-RAOB2

This program calculates the u- and v-components of the 850-mb and surface wind data (in meters per second) extracted by PGM-RAOB. It then grids these values by the methods described in PGM-SFC2. Although it is possible to use the surface wind data extracted from the upper air data tapes (input file = logical unit 10), we recommend that surface winds from the surface observation tapes be used, because of the significantly higher number of sites available. Files are assigned to the following logical unit numbers: 10 = ASCII input file (TGOOD) from PGM-RAOB; 11 = binary input file (WSAVE) from PGM-RAOB; 15 = output, gridded 850-mb u-components (in meters per second); 16 = output, gridded 850-mb v-components (in meters per second). Other files that are generated include 12, which outputs mixing heights (in meters), and 13 and 14, which are the gridded surface u- and v-components (in meters per second), respectively (obtained from input file 10). These files may be used by setting certain logical options to .TRUE. in the subroutine DEFALT in the RELMAP model. Table 4.6 is the input card image for this program.

TABLE 4.6. INPUT CARD IMAGE FOR PGM-RAOB2

Record Type	Number of Records	Variable	Description	Units	Format/Type
1	1	MDATE	Starting date-time in the form YYMMDDHH	GMT	I8

PGM-TIME

This program interpolates or sums gridded data from their original time steps to the user-specified time step. This program is used twice, once for upper air wind data and once for surface wind data (see Figure 4.1). The only restriction is that the original time step must be a whole number multiple of the desired time step or vice versa. For example, the sample problem in Section 5 uses a time step of 3 h. Thus, we use PGM-TIME to convert 12-h upper air data and 6-h surface data to 3-h increments. The input file (logical unit 10) is the output file from either PGM-RAOB2 or PGM-SFC2. The output file (logical unit 11) has the same format as the input file to this program. Table 4.7 is the input card image for this program.

TABLE 4.7. INPUT CARD IMAGE FOR PGM-TIME

Record Type	Number of Records	Variable	Description	Units	Format/Type
1	1	FNAME	Output file name	--	C*28
2	1	NT	Old time interval	h	I2
3	1	NEWT	New time interval	h	I2

Precipitation Data

The preprocessor programs for precipitation data are designed to combine data from U.S. and Canadian sources. Neither NCDC nor the Canadian Meteorological Center provide station precipitation data on one tape. It is necessary to request separate precipitation data files and station locator files from both agencies. Also, the Canadian precipitation data file consists of two data sets: (1) hourly data, and (2) daily data. These data sets do not contain redundant information, that is, no sites report both hourly and 24-h values. The preprocessor assumes that both Canadian data sets reside in one file with 704 blocks of data (daily first, then hourly values). The user will also need data on cloud cover (for program HOLEZ). These data are obtained from the output file called SKY-DAT (generated by PGM-SFC2), which gives gridded cloud coverage data. The final product of the preprocessed precipitation data is a file called PRECIP-DAT, which is an input file to the RELMAP model.

U.S. Precipitation Data

LOCATR--This program reads the station locator tape and assigns latitude-longitude coordinates to all stations. (If ATAPE is used, the internal file name TAPEA is assigned to the tape.) It produces an unformatted binary file (logical unit 10) that is used as input for MASTER and prints a listing of the data in the unformatted file. This program does not require card image input.

MASTER--This program combines the original precipitation data tape file with the unformatted output file from LOCATR (logical unit 10). As received, the precipitation data tape only lists the days on which precipitation was measured. Thus, frequent gaps occur that represent days on which no precipitation was measured. This program produces a restructured tape file that smooths out any gaps in the precipitation data by adding in the missing days and assigning them values of zero for precipitation amount. It also associates the precipitation values with their stations. MASTER does not require card image input.

RTREV--This program extracts hourly U.S. precipitation data for the time period and domain specified by the user. The input file is the output file produced by MASTER. The unformatted binary output file (logical unit 10) contains hourly U.S. precipitation data from the stations within the user-specified domain for the user-specified time period. Table 4.8 is the input card image for this program.

TABLE 4.8 INPUT CARD IMAGE FOR RTREV

Record Type	No. of Records	Variable	Description	Units	Format/Type
1	1	IDATE1	Start date (YYMMDD)	--	I6
		IDATE2	Stop data (YYMMDD)	--	I6

SORT--This routine is UNIVAC-specific, so the non-UNIVAC user will have to substitute a sorting routine from his system. Before SORT, the data are in chronological order by station. This routine sorts the data into a chronological synoptic file by date and time. This is done by sorting the first six characters of each record, which contain the date and time. The output of this SORT routine is combined with the output from the SORT routine of the Canadian data in a program called GRID.

Canadian Precipitation Data

C-LOCAT--This program reads the station locator file and assigns latitude-longitude coordinates to all stations. It produces an unformatted binary output file (logical unit 10) that is used as input for CANRAIN. This program does not require user input.

CANRAIN--This program first combines the precipitation data tape file with the unformatted output file from C-LOCAT (logical unit 10). It fills in gaps in precipitation data by the same method as MASTER. As with MASTER, CANRAIN also associates the precipitation data with their corresponding stations. CANRAIN then converts the 24-h data to hourly data (by assuming a uniform distribution over a 24-h period) and extracts precipitation data for the time period and domain specified by the user. In doing so, it produces two output files: (1) an unformatted binary file (logical unit 11) of the 24-h Canadian precipitation data (converted to hourly values) from the stations within the user-specified domain for the user-specified time period, and (2) an unformatted binary file (logical unit 12) of the hourly Canadian precipitation data from the user-specified domain for the user-specified time period. Table 4.9 is the input card image for this program.

TABLE 4.9 INPUT CARD IMAGE FOR CANRAIN

Record Type	No. of Records	Variable	Description	Units	Format/Type
1	1	IDAT1	Start date (YYMMDD)	--	I6
		IDAT2	Stop date (YYMMDD)	--	I6

SORT--As for the U.S. data, the Canadian data must be sorted (by a computer-specific routine) into a chronological synoptic file by date and time. The output of this routine (still in two separate files) is combined with the output from the SORT routine of the U.S. data in a program called GRID.

GRID--This program combines and grids the sorted U.S. and Canadian precipitation data for the user-specified time period. It provides precipitation values only for those grid cells that contain reporting stations. The next program (HOLEZ) assigns precipitation values to all grid cells in the domain. GRID reads three input files: (1) U.S. hourly precipitation data (logical unit 10), (2) Canadian hourly precipitation data (logical unit 13), and (3) Canadian 24-h precipitation data, converted to hourly values (logical unit 14). The program produces two output files: (1) combined and gridded precipitation amounts for the user-specified time period (logical unit 11), and (2) combined and gridded counts of reporting stations per grid cell for the user-specified time period (logical unit 12). Table 4.10 is the input card image for this program.

TABLE 4.10 INPUT CARD IMAGE FOR GRID

Record Type	No. of Records	Variable	Description	Units	Format/Type*
1	1	FHED	Output file name	--	C*28
2	1	INC	Time increment of output grids	h	I
3	1	ACONS	Multiplier factor to adjust data to millimeters	--	FN.N
4	1	ICAN1	Inclusion of hourly Canadian precipitation data: 1 = yes; 2 = no	--	I
5	1	ICAN2	Inclusion of daily Canadian precipitation data: 1 = yes; 2 = no	--	I

*Free format.

HOLEZ--This program assigns precipitation values to those grid cells that do not contain a reporting station. It requires three input files: (1) the gridded counts of stations (logical unit 10), produced as output by GRID, (2) the gridded precipitation amounts (logical unit 11), produced as output by GRID, and (3) gridded cloud cover values (logical unit 12), produced as output by PGM-SFC2. The program uses the Barnes method (described in PGM-SFC2) with gridded values of cloud cover and counts of reporting stations to calculate average rainfall for the grid cells that do not contain precipitation data. HOLEZ uses two subroutines, BARNES and GRIDZ, that contain PARAMETER statements that must be changed if the user alters the domain from its default values. HOLEZ produces an unformatted file (attached to logical unit 13) that contains gridded precipitation rates (in millimeters per hour) for all grid cells within the user-specified domain for the user-specified time period and prints a listing (up to 15 columns on a page) of the total precipitation amounts, summed for each grid cell, for the entire user-specified time period. The unformatted output file is used as an input file by the RELMAP model. HOLEZ does not require user input.

Emissions Data

Emissions data for the United States and Canada may be obtained from the EPA's Office of Air Quality Planning and Standards (OAQPS) and Environment Canada (EC), respectively. Emissions data for 1980 for both the United States and Canada, in the format of the Emission Inventory System (EIS) (McMaster, 1980), can be obtained from the Environmental Monitoring Laboratory (EMSL) of the U.S. EPA. Table 4.1 contains the addresses for OAQPS, EC, and EMSL. If data for a fairly large geographic area are requested, the user will probably receive a number of tapes (sorted by state or province), because of the large volume of information included for each area. The preprocessor for emissions data (initially in metric tons per year) processes point-source and area-source data separately until the final program (MERGE) combines the two sources into one file that is used by the RELMAP model (EMISSION-DAT, in which emissions are in kilotons per hour).

Point-Source Emissions

PACK-POINT--This program extracts the data required by the RELMAP model from the point-source emissions tape provided by OAQPS. This program must be run for each OAQPS data tape. The user must then concatenate the files to create one file for use by the next emissions preprocessor program, RTREVP. The internal file name for the input file is PTTAPE. The output file is written to logical unit 12. Table B.5, in Appendix B, contains the output format for this program.

RTREVP--This program extracts the emissions data, for a user-specified geographic area and for user-specified pollutants, from the file produced by PACK-POINT. The input file is attached to logical unit 9, and the output file is attached to logical unit 10. The output file is in the same format as the input file, but it only contains data on user-specified pollutants in the user-specified domain. Table 4.11 reproduces the input messages to which the user must respond in this program. The messages in this table also apply to RTREVA.

RELMAPP--This program reformats the file produced by RTREVP into a format compatible with the RELMAP model. Also, if the user chooses, this program will grid the point-source emissions.

NOTE: If the user wants merged point-source and area-source emissions data, he must choose the option for gridded data.

If the user specifies the source-receptor output format of the RELMAP model (see description in Section 1), he must divide the domain into the desired number of emissions regions from which he wants gridded data. To do so, he must provide an additional input file (called REGIONS) that describes the portion of the domain occupied by each region by assigning an integer to each grid cell to indicate its regional identity. This optional input file is attached to logical unit 8. The input file, produced as output by RTREVP, is assigned to logical unit 9, and the output file is attached to logical unit 10. Table 4.12 reproduces the input messages to which the user must respond in this program. The messages in this table also apply to RELMAPA.

TABLE 4.11. USER INPUT TO RTREVP AND RTREVA*

Message Number	Message	User Options
1	If you want to define a specific area, enter a 1; if you want all areas, enter a 2	If you enter a number > 1, go to Message 12; if you enter a number < 1, go to Message 2
2	If you want to define an area by specifying the latitudes and longitudes, enter a 1; otherwise, enter a 2	If you enter a number > 1, go to Message 5; if you enter a number < 1, go to Message 3
3	Enter latitude, then longitude of southwest corner of area (decimal degrees)	Enter correct latitude and longitude
4	Enter latitude, then longitude of northeast corner of area (decimal degrees)	Enter correct latitude and longitude; go to Message 12
5	If you want to define an area by UTM** coordinates, enter a 1; otherwise, enter a 2	If you enter a number > 1, go to Message 9; if you enter a number < 1, go to message 6
6	Specify UTM** zones of interest; enter up to 10 zones, one at a time; end with a negative number	If you try to enter more than 10 zones or you enter a negative before the tenth zone, you'll get an error message; after you enter a zone, go to Message 7
7	For this UTM** zone, enter minimum and maximum horizontal coordinates	After you enter coordinates, go to Message 8
8	For this UTM** zone, enter minimum and maximum vertical coordinates	After you enter coordinates, enter next UTM zone, and go back to Message 7
9	If you want to define an area by state, enter a 1; otherwise, you must identify the area by state and county and enter a 2	If you enter a number > 1, go to Message 11; if you enter a number < 1, go to Message 10
10	Specify states of interest by state number, one at a time, ending with a negative number	Maximum of 50 numbers possible; go to Message 12
11	Specify state number, then county number, of each county of interest; enter one state-county combination at a time; end with a negative number; maximum of 500 entries	Separate entries by blanks, commas, or by putting them on different lines; after 500 entries or an final negative entry, go to Message 12
12	If you are interested in the maximum number of pollutants (15), enter a 1; otherwise, enter a 2	If you enter a 1, go to Message 13; any other number will elicit no further messages
13	No more than 15 pollutants may be selected; consult AEROS Manual (EPA, 1976) for code numbers; 8 of the more common pollutants are listed below: 11101 -- Total suspended particulate matter 12128 -- Particulate lead 12403 -- Particulate sulfate 42101 -- Carbon monoxide 42401 -- Sulfur dioxide 42602 -- Nitrogen dioxide 42604 -- Ammonia 43101 -- Total hydrocarbons Enter pollutant number, one at a time, end with a negative number	Program will continue to prompt for numbers till a negative number or 15 positive numbers are read

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* Responses in free format.

** UTM = Universal Transverse Mercator.

TABLE 4.12. USER INPUT TO RELMAPP AND RELMAPA*

Message Number	Message	User Options
1	If you want gridded emissions, enter a 1; otherwise, enter a 2	If you enter a number > 1, go to Message 2; if you enter a number < 1. to to Message 3
2	Specify the minimum amount you will accept from a point source, in tons per year	Enter number; go to Message 3
3	Enter number of emission regions, maximum = 90	If you enter a number < 1, go to Message 5; if you enter a number > 1, go to Message 4
4	Enter region names, one at a time up to 80 characters	Program will continue to prompt for names until reaches number specified in response to Message 3, then to to Message 5
5	Enter season code: 1 = winter; 2 = spring; 3 = summer; 4 = autumn	Enter number, then go to Message 6
6	If you want data on sulfates only, enter a 1; if you want sulfates and particulate matter, enter a 2	Enter number, then go to Message 7
7	Enter output file name--80 characters or less	Enter name; end of messages

* Responses are in free format.

Area-Source Emissions

PACK-AREA--This program extracts the data required by the RELMAP model from the area-source emissions tape provided by OAQPS. This program must be run for each OAQPS data tape. The user must then concatenate the files to create one file for use by the next emissions preprocessor program, RTREVA. The internal file name for the input file is ARTAPE. The output file is written to logical unit 13. Table B.6, in Appendix B, contains the output format for this program.

RTREVA--This program extracts the emissions data, for a user-specified domain and for user-specified pollutants, from the file produced by PACK-AREA. Area-source emissions are reported as one value per county. To assign geographic coordinates to these values, we provide the user with an input file called COUNTY LOCATIONS (logical unit 11), which must be read into RTREVA. The input file produced by PACK-AREA is attached to logical unit 9, and the output file is attached to logical unit 10. The output file is in the same format as the input file, but it only contains data on user-specified pollutants in the user-specified domain. Table 4.11 reproduces the input messages (same as for RTREVP) to which the user must respond in this program.

RELMAPA--This program reformats the file produced by RTREVA into a format compatible with the RELMAP model. Also, if the user chooses, this program will grid the area-source emissions.

NOTE: If the user wants merged area-source and point-source emissions data, he must choose the option for gridded data.

To grid area-source emissions, the county-wide values must be assigned to specific geographic locations. As for RTREVA, we provide the user with an input file called COUNTY LOCATIONS (attached to logical unit 11) to assign geographic coordinates to the data. As for RELMAPP, if the user wants gridded data for more than one region (for source-receptor output mode), then he must provide another input file (called REGIONS) that describes the portion of the domain occupied by each region by assigning an integer to each grid cell to indicate its regional identity. This optional input file is assigned to logical unit 8. The input file for this program, produced as output by RTREVA, is attached to logical unit 9, and the output file is attached to logical unit 10. Table 4.12 reproduces the input messages (same as for RELMAPP) to which the user must respond in this program.

MERGE--This file merges the gridded output files produced by RELMAPP and RELMAPA into one file of gridded point-source and area-source emissions. As they are merged, individual records of both data sets are compared; discrepancies are noted by error messages. The input file of point-source emissions is attached to logical unit 10, and the area-source emissions input file is attached to logical unit 11. The output file of merged emissions data is attached to logical file 12. This output file (EMISSIONS-DAT) is used as input to the RELMAP model.

Dry Deposition Velocities

This branch of the preprocessor requires no raw data. It consists of one program that produces dry deposition velocity files for four pollutants (SO_2, $SO_4^=$, 2.5- μ m particles, and 10- μ m particles) for four seasons. The file names are as follows: DRYDEP1-DAT for SO_2, DRYDEP2-DAT for $SO_4^=$, DRYDEP3-DAT for fine particles, and DRYDEP4-DAT for coarse particles. These dry deposition velocity files are used as input by the RELMAP model.

DEPPUFP--This program contains files of seasonal dry deposition velocities for four pollutants: SO_2, $SO_4^=$, 2.5- μ m particles, and 10- μ m particles (see values in Tables 2.5-2.7 in Section 2). The program contains an array of dry deposition velocities for each pollutant based on land use category and stability category (see Tables 2.5-2.7 in Section 2). If the user defines his domain to include areas outside the current domain, then he will have to replace the land use categories in the array called IREG with new categories on a grid cell by grid cell basis. If the user opts to remain with the current domain, then he must simply specify (1) the season, (2) whether or not he wants velocities for particulate matter, and, if so, (3) what size of coarse particles are of interest. The program produces up to four output files, as shown in Table 4.13. These files are used as input to the RELMAP model. Table 4.14 is the input card image for this program.

TABLE 4.13. OUTPUT FILES PRODUCED BY DEPPUFP

File Name	Logical Unit No.	Description
DRYDEP1-DAT	10	Dry deposition velocities for SO_2
DRYDEP2-DAT	11	Dry deposition velocities for $SO_4^=$
DRYDEP3-DAT	12	Dry deposition velocities for 2.5- μ m particles
DRYDEP4-DAT	13	Dry deposition velocities for 10- μ m particles

TABLE 4.14. INPUT CARD IMAGE FOR DEPPUFP

Record Type	Number of Records	Variable	Description	Units	Format/Type
1	1	SEASON	Name of season: SPRING, SUMMER, AUTUMN or WINTER	--	C*6
2	1	ANS	Inclusion of particulate matter: YES or NO (Y or N)	--	A1
3	1	IPART	Representative size of coarse particulate matter: 1 = 5 μ m 2 = 10 μ m 3 = average of two values above	--	I

Source Region for Source-Receptor Mode

WNDO-FIL--If the user has chosen the output format of the RELMAP model called source-receptor mode (see description in Section 1), he must create another input file for the model. The program WNDO-FIL assigns all grid cells in the user-specified domain to user-specified receptor regions. The program prompts the user to assign (in free format) non-zero integer values to each grid cell in his domain. A value of zero means the grid cell is not assigned to any region. The output file (logical unit 10) is called WINDOW-DAT; it serves as an input file for the RELMAP model, when the source-receptor output mode is selected.

THE RELMAP MODEL

The RELMAP model itself consists of one primary program (MAIN) and 17 subroutines, which are called by MAIN. Figure 4.2 illustrates the structural interrelationships between MAIN and its major subroutines.

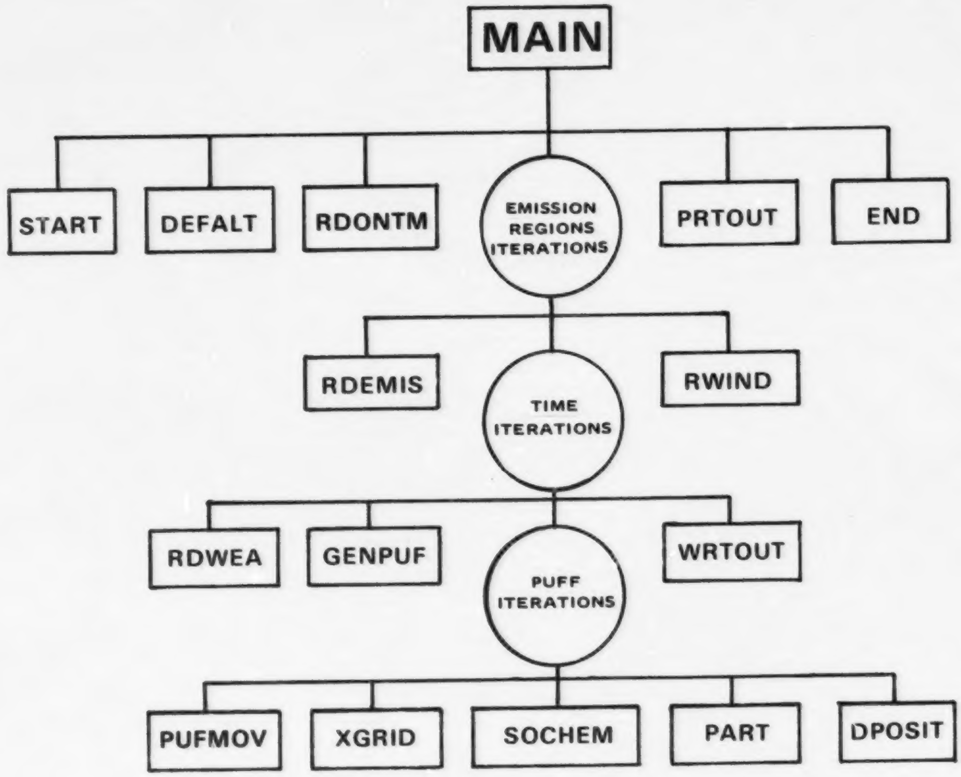
MAIN
START
DEFALT
RDONTM
EMISSION REGIONS ITERATIONS
PRTOUT
END
RDEMIS
TIME ITERATIONS
RWIND
RDWEA
GENPUF
PUFF ITERATIONS
WRTOUT
PUFMOV
XGRID
SOCHEM
PART
DPOSIT

Figure 4.2. Structure diagram of subroutines used in RELMAP.

MAIN

Besides calling the subroutines, this program performs a number of other functions:

- Determines when puffs should be generated and when results should be written out,
- Keeps track of the number of puffs existing simultaneously in the domain and handles the I/O chores of reading them in and writing them out,
- Keeps the "puffs-outside-domain" portion of the sulfur budget current,
- Implements the chosen output mode,
- Defines the daytime vertical profile of pollutants,
- Writes out a fail-safe file after each emission region is processed,
- Contains all COMMON blocks used by the model to pass information.

The Subroutines

DEFALT

This subroutine contains all user inputs into the model, except for data sets. It reads the input file called INPUT-DAT that contains the values of all variables that may be changed by the user (described subsequently). In the code, these variables are located in a NAMELIST called CARD. Any non-zero number of variables may be assigned new values by using NAMELIST READ conventions. DEFALT provides detailed instructions on how to change variables.

RDONTM

Some input data arrays are read only once per model execution, and others are read repeatedly. From the options chosen in DEFALT, this subroutine reads certain one-time data arrays from either user-created files or outside data sources. The arrays that may be read are DRYDEP1-DAT, DRYDEP2-DAT, DRYDEP3-DAT, DRYDEP4-DAT, WINDOW-DAT, and MIXHT2-DAT.

RDEMIS

For each source in each emission region, this subroutine converts the emission rate given in the input file to kilotons per year. Then it assigns grid cell coordinates to the center of each puff, computes the radius of each puff, and stores the results in a COMMON block called EMIS.

RDWEA

From the options chosen in DEFALT, this subroutine either reads files for wind data, mixing heights, stability categories, and precipitation data or it generates default arrays for data files not provided by the user. If a user-provided data set runs out of data before the end of the modeling period, then the array for the previous time step becomes the default array for the remaining time.

GENPUF

This subroutine generates new puffs of pollutants for each source in each region per time step at the interval specified by the user in INPUT-DAT. The variable name for this interval is IPUFNC, and the default value is 12 h.

PUFMOV

This subroutine moves all existing puffs each time step. With each move, it recomputes each puff's radius and geographic location.

XGRID

For each puff, this subroutine calculates the percentage of the cross-sectional area of the puff contained in each grid cell covered by the puff. If the puff is entirely within one grid cell (no matter how much of that cell is actually covered), then that cell is assigned a value of 100%.

SOCHEM

For each puff, this routine calculates the transformation rate of SO_2 to $SO_4^=$ and the amount of SO_2 transformed. Next, it calculates pollutant mass (as percentage of each grid cell covered by a given puff and the amount in that puff) and the amounts of wet and dry deposition.

PART

This subroutine is analogous to SOCHEM. For each puff, it calculates the concentration and amounts of wet and dry deposition of fine and coarse particulate matter.

DPOSIT

This subroutine assigns geographic locations to the data generated by SOCHEM and/or PART.

WRTOUT

If the user specifies a non-zero number less than the number of days in the month (zero = monthly) for the variable FDAILY in the INPUT-DAT file, then this subroutine writes out array summaries at intervals equal to the number of days represented by the specified number.

AMATRX

If the user selects source-receptor matrices (see description in Section 1) as the output format, this subroutine assists in the calculation of those matrices.

RWIND

This subroutine rewinds the files used by REDWEA after each emitting region is processed.

DAYNIT

For each puff for each time step, this subroutine determines whether it is day or night at the puff's location.

PRORAT

If the user inputs layered emissions, then this subroutine prorates those data so that they correspond to the layers used by the model.

HGTADJ

This subroutine supplies values for mixing height, which varies diurnally, and stability index, which varies diurnally and seasonally.

PRTOUT

This subroutine prints out the results of the simulation in one of the two possible output formats that may be specified by the user: (1) arrays of gridded values of ambient concentrations and wet and dry deposition of specified pollutants, and (2) source receptor matrices.

Input and Output Files

INPUT FILES

The model uses preprocessed data files and the file that contains user input (INPUT-DAT) read by the subroutine DEFALT. Table 4.15 summarizes these

TABLE 4.15. INPUT FILES TO THE RELMAP MODEL

Required Name	Logical Unit No.	Description
INPUT-DAT	10	This file is read by the RELMAP subroutine called DEFALT. It contains all the user-supplied input required by the model (see Table 4.16).
UPRWNDUU-DAT	14	This file contains the u-components of the 850-mb winds. It is generated as output by the preprocessor of upper winds.
UPRWNDVV-DAT	16	This file contains the v-components of the 850-mb winds. It is generated as output by the preprocessor of upper winds.
LWRWNDUU-DAT	17	This file contains the u-components of the surface winds. It is generated as output by the preprocessor of surface winds.
LWRWNDVV-DAT	18	This file contains the v-components of the surface winds. It is generated as output by the preprocessor of surface winds.
PRECIP-DAT	26	This file contains the precipitation data generated as output by the preprocessor of precipitation data.
EMISSION-DAT	20	This file contains the emissions data generated as output by the preprocessor of emissions data.
DRYDEP1-DAT	21	This file contains the dry deposition velocities for SO_2 generated by DEPPUFP in the preprocessor.
DRYDEP2-DAT	22	This file contains the dry deposition velocities for $SO_4^=$ generated by DEPPUFP in the preprocessor.
DRYDEP3-DAT	9	This file contains the dry deposition velocities for fine particles generated by DEPPUFP in the preprocessor.
DRYDEP4-DAT	27	This file contains the dry deposition velocities for coarse particles generated by DEPPUFP in the preprocessor.
WINDOW-DAT	23	This file is required for the source-receptor output mode. It contains the data generated by WNDO-FIL in the preprocessor.

input files and gives their logical unit numbers. All of these files are the output files generated by the preprocessors, except for INPUT-DAT.

INPUT-DAT--This file contains the values of the variables in the model that can be changed by the user. In the code, these variables are located in a NAMELIST called CARD. Any number of variables may be assigned new values by using NAMELIST READ conventions. The subroutine DEFALT, which contains this file, provides detailed instructions on how to change variables. Table 4.16 contains a description of the variables that may be altered in this file, including their default values. These default values are used if the user does not specify a different value.

This input file provides the user with a number of options. For example, if the user's mixing height data are not formatted by the preprocessor, but are given as minimum and maximum values for each grid cell, then he should set the variable FMXONT = .TRUE. If the user's emissions data are assigned to three layers (different from the model's layers), then he should reset the values for the following variables: FEMITL, EMITL, EMITM, and EMTH. The model assumes instantaneous mixing of pollutants in three layers during the daytime. If the user wishes to redefine the vertical daytime profile of the mass of the pollutants, then he should reset the following variables: FPROF, PR1, PR2, PR3, and PR4. The default values of these variables reflect instantaneous mixing.

Additionally, manipulation of certain variables in INPUT-DAT will produce different kinds of simulations:

(1) To produce output in source-receptor mode, alter FMATRX, NREG, NEMIT, FEMIT, and FWINDO.

TABLE 4.16. INPUT-DAT VARIABLES

Variable	Description	Units	Default Value
MONNUM	Month-number for this run (1-12)	--	1
IYEAR	Year (four digits, e.g., 1980	--	1978
IDELAY	Number of days delay built in (to allow puffs to assume a good distribution) before computations begin	--	4
IHRINC	Time increment of the computations	h	2
IPUFNC	Puff-generation interval	h	12
EXPRAT	Expansion rate of the puff	km^2/h	339.0
FMATRX	For source-receptor output mode, option to calculate source-receptor data: TRUE = Calculate data, FALSE = Do not calculate data	--	FALSE
NREG	Number of receptor regions (for source-receptor output mode)	--	1
NEMIT	Number of source regions (for source-receptor output mode)	--	1
FDAILY	Number of consecutive days (in each period when results are printed) of data to accumulate before writing it out (0 = monthly, N = N days)	--	0
NPOL	Number of pollutant species evaluated	--	4
POLNAM	Pollutant names: SOX = SO_2 and $SO_4^=$ only; DIRT = SOX and particulate matter	--	SOX
AMN1	Minimum amount of SO_2 allowed before the puff is dropped	ktons	0.5×10^{-4}
AMN2	Minimum amount of $SO_4^=$ allowed before the puff is dropped; the conditions for AMIN1 and AMIN2 must both be satisfied before the puff is dropped.	ktons	0.5×10^{-4}
AMN3	Minimum amount of 2.5- μ particles allowed before the puff is dropped	ktons	0.5×10^{-4}
AMN4	Minimum amount of 10- μ particles allowed before the puff is dropped; if either conditions for AMIN3 or AMIN4 are met, the puff is dropped.	ktons	0.5×10^{-4}
PP	Default amount of precipitation in each grid square for each time period	cm	0.5
D1	Default dry deposition rate for SO_2 (each grid square, each time period)	ktons/h	0.6
D2	Default dry deposition rate for $SO_4^=$ (each grid square for each time period)	ktons/h	0.4

TABLE 4.16. INPUT-DAT VARIABLES (CONTINUED)

Variable	Description	Units	Default Value
D3	Default dry deposition rate for 2.5- μ particles (each grid square, each time period)	ktons/h	0.4
D4	Default dry deposition rate for 10- μ particles (each grid square, each time period)	ktons/h	0.1
UPRWND	Availability of upper air wind data: TRUE = Data will be read in for each time period; FALSE = Data will not be read in	--	FALSE
LWRWND	Availability of surface wind data: TRUE = Data will be read in for each time period; FALSE = Data will not be read in	--	FALSE
FMXHT	Availability of mixing height data: TRUE = Data will be read in for each time period; FALSE = Data will not be read in	--	FALSE
FSTAB	Availability of stability index data: TRUE = Data will be read in for each time period; FALSE = Data will not be read in	--	FALSE
FPRCP	Availability of precipitation data: TRUE = Data will be read in for each time period; FALSE = Data will not be read in	--	FALSE
FMXONT	Availability of maximum and minimum mixing height data: TRUE = Data will be read in one time at the beginning of the computations; FALSE = Data will not be read in	--	FALSE
FDRYP1	Availability of dry deposition data for SO_2: TRUE = Data will be read in for each grid square before computations begin; FALSE = Data will not be read in	--	FALSE
FDRYP2	Availability of dry deposition data for $SO_4^=$: TRUE = Data will be read in each grid square once only before computations begin; FALSE = Data will not be read in	--	FALSE
FDRYP3	Availability of dry deposition data for 2.5- μ particles: TRUE = Data will be read in each grid square once only before computations begin; FALSE = Data will not be read in	--	FALSE

TABLE 4.16. INPUT-DAT VARIABLES (CONTINUED)

Variable	Description	Units	Default Value
FDRYP4	Availability of dry deposition data for 10-μ particles: TRUE = Data will be read in each grid square once only before computations begin; FALSE = Data will not be read in	--	FALSE
FEMITL	Availability of raw emissions data assigned to three layers: TRUE = Layered emissions available; FALSE = Layered emissions not available	--	FALSE
EMITL	If layered emissions, height of lowest layer	m	200.0
EMITM	If layered emissions, height of middle layer	m	700.0
EMTH	If layered emissions, height of highest layer	m	1150.0
AMIXH	Default maximum mixing height for each grid square for each time period	m	1150.0
AMIXL	Default minimum mixing height for each grid square for each time period	m	50.0
VUSPD	Default v-component of upper wind data for each grid square for each time period	m/s	0.0
UUSPD	Default u-component of upper wind data for each grid square for each time period	m/s	10.0
VLSPD	Default v-component of surface wind data for each grid square for each time period	m/s	1.0
ULSPD	Default u-component of surface wind data for each grid square for each time period	m/s	5.0
RESUME	Availability of puff positions from previous month: TRUE = Data have been saved and will be used as starting conditions for this run; FALSE = Data have not been saved	--	FALSE
FWINDO	For source-receptor output mode, availability of grid square assignments to emission sources: TRUE = Data will be read in; FALSE = Data will not be read in	--	FALSE

TABLE 4.16. INPUT-DAT VARIABLES (CONTINUED)

Variable	Description	Units	Default Value
FEMIT	For source-receptor output mode, availability of list of emission rates for each source in each emission region: TRUE = Data will be read in; FALSE = Data will not be read in	--	FALSE
F1LYR	Option of using a one-layer model instead of a three-layer model: TRUE = Run model with one layer; FALSE = Run model with three layers	--	FALSE
IHRITE	Defines when an optional file (more frequent time interval) will be written out (used with FDAILY and RESUME); default value is last hour of a non-leap year	h	8784
FRATD	Option to alter constants in nighttime dry deposition rate equations: TRUE = Alter the constants; FALSE = Do not alter the constants	--	FALSE
AD1	Nighttime dry deposition rates for SO_2, $SO_4^=$, and fine particulate matter	%	0.0126
FPROF	Option to define vertical daytime profile of the mass of the pollutants: TRUE = Define profile; FALSE = Do not define profile	--	FALSE
PR1,PR2, PR3,PR4	Vertical daytime profile, must sum to 1.00	%	8.6956518×10^{-3}, 0.1652174, 0.4347826, 0.3913043

(2) To produce arrays of gridded values of ambient concentrations and wet and dry deposition of pollutants, leave the default values in place.

(3) For a faster computer run time, the user might want to use a one-layer rather than a three-layer model. To do so, set F1LYR=.TRUE.

(4) To run the model for a period shorter than one month, reset FDAILY and IHRITE.

(5) To run the model for particulate matter and SO_2 and $SO_4^=$, set FPART = .TRUE., and assign POLNAM any name other than SOX.

It is possible to combine Option 1 with Options 3-5 or Option 2 with Options 3-5. Options 1 and 2 are mutually exclusive. Careful examination of the variables in INPUT-DAT will provide the user with more ways to change the model to best fit his needs.

OUTPUT FILES

Table 4.17 summarizes the output files of the model. Most of these files are used internally. TEST-LIS is the primary output file of the model. Results are written to this file.

TABLE 4.17. OUTPUT FILES GENERATED BY RELMAP*

Required Name	Logical Unit No.	Description
SCRTCH1-DAT	12	This file is used with SCRATCH2-DAT to handle individual puffs so that the model can allow an almost unlimited number of puffs to exist simultaneously. Puffs are read into one file, for example, SCRATCH1-DAT, and if they still exist at the end of a time interval, then they are written to the other file (SCRATCH2-DAT). Then the files are reversed, and the puffs are read back again on the next time step.
SCRTCH2-DAT	13	See description for SCRATCH1-DAT.
SAFE-DAT	36	This is a fail-safe device that writes out all puff locations and all results after each emission region is processed.
MATRIX-DAT	11	When the source-receptor output mode is selected, this file is used as a scratch file for source-receptor data.
TEST-LIS	31	This is the primary output file of the model. All messages and results are written here.

* If FDAILY > 0, then four more output files are required: SCRTCH3-DAT (logical unit 2), SCRTCH4-DAT (logical unit 3), SCRTCH5-DAT (logical unit 7), and SCRTCH6-DAT (logical unit 8). These are working files only.

SECTION 5

EXAMPLE EXECUTION

An example execution of the RELMAP model and its preprocessors is provided. The Executive Control Language (ECL) of the UNIVAC system is used. For this example execution, the preprocessors and both output versions of the model are run for the month of January, 1980 for a 12 x 13 window located within the model's default domain (Figure 5-1). This window, which contains a total of 156 grid cells, ranges from 30° to 43°N and from 80° to 92°W.

Figure 5.2 is an annotated PRECIS of the tape provided with the user's guide that contains the programs and data files. It contains a brief description of the 14 files on the tape. The first four files are program files that contain the program elements for the model and the preprocessors, and the 10 remaining files contain the data.

The preprocessors used for the emissions data have been omitted in this example execution. Instead, the final preprocessed emissions file provided on the tape (File 6) is ready as direct input into the model. The programs used for preprocessing the emissions data, which are located on the fourth file of the tape, are discussed in Section 4. Also, because the grid used in the example execution does not extend far into Canada, the two files on the tape that contain the Canadian precipitation data (File 13) and the Canadian stations (File 14) are not accessed by the precipitation preprocessors in this example.

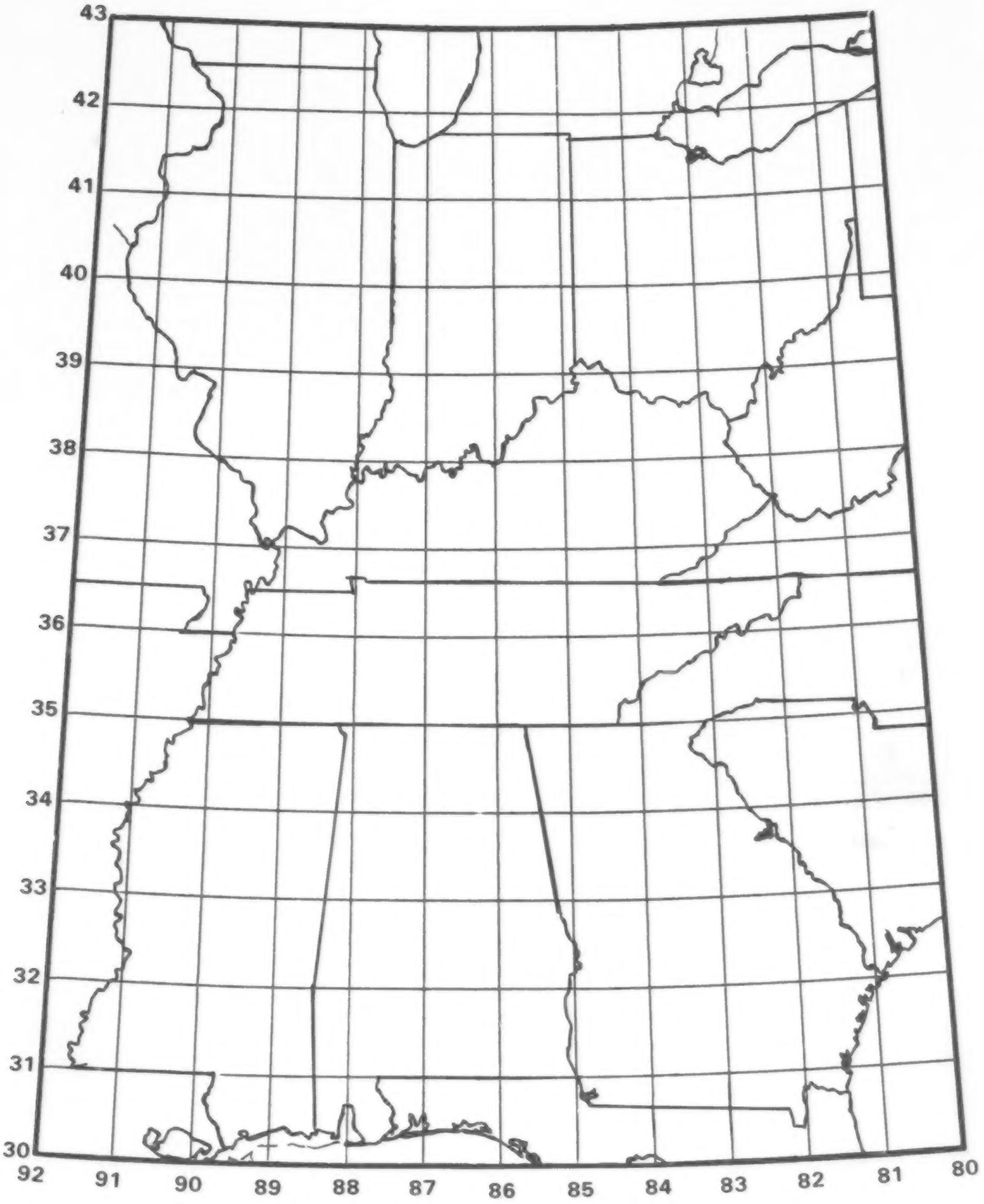
43
42
41
40
39
38
37
36
35
34
33
32
31
30
92
91
90
89
88
87
86
85
84
83
82
81
80

Figure 5.1. Subgrid (12 x 13) used in the example execution.

```
VOLUME  QUALIFIER     FILENAME     ATTRIBUTES   DATE       TIME      PAGE
000123  EMAP          OMEWND       6250,9,0,8   12 DEC 85  11:46:47  1
                                                                                   FILE CONTENTS
FILE     LONGEST  SHORTEST  BLOCK      FEET USED   RECORD SIZE
NUMBER   BLOCK    BLOCK     COUNT      (NOMINAL)    (Bytes)
        (Words)  (Words)
1        2000     1280      53            8.7        80       RELMAP Model Program Files (18 Elements)
2        2000     500       32            5.6        80       Surface, Upper-Air Preprocessor Program Files (13 Elements)
3        2000     320       24            4.4        80       Precipitation Preprocessor Program Files (20 Elements)
4        2000     1600      32            5.6        80       Emissions Preprocessor Program Files (13 Elements)
5        400      400       1             1.0        80       INPUT-DAT
6        2250     766       7             2.0        90       EMISSION-DAT
7        260      260       1             1.0        80       WINDOW-DAT
8        2000     620       32            5.6        80       County Location Data File for Area Emissions
9        1610     58        3637        349.6      6440       Surface Data File (ASCII Characters)
10       1610     26        951          96.0      6440       Upper-Air Data File (ASCII Characters)
11       3000     1520      323          67.8        80       U. S. Hourly Precipitation Data File (ASCII Characters)
12       200      20        5745        225.7        80       U. S. Station Location Data File (ASCII Characters)
13       4640     464       1430        435.5      1856       Canadian Precipitation Data File (ASCII Characters)
14       2000     1000      50            8.2        80       Canadian Station Location Data File (ASCII Characters)
** END-OF-VOLUME **                TOTAL  1217.3
```

Figure 5.2. Annotated precis of tape.

In the example runstreams presented, we assumed that the user has successfully loaded, compiled, and mapped all of the program elements, and that all of the data files have been successfully transferred from the tape to the system disk. The user should now be ready to run the preprocessors in the sequence presented.

The runstreams that make up this example execution use ECL and should be copied exactly if the user is operating on a Sperry UNIVAC. Otherwise, they should be translated into comparable statements on other computer systems. The ECL commands used here include (@ASG), which assigns program and data files to the run; (@USE), which attaches file names to logical unit numbers and assigns aliases; and (@XQT), which initiates program execution. After execution, the user is often prompted for a response (this prompt is represented by italicized type in the runstreams). Responses should be supplied in the format illustrated by the input card images described in Section 4.

PGM-SFC1

The following runstream illustrates the procedure used to mount the tape and execute PGM-SFC1, which reads the ninth file on the tape. This file contains surface data and generates two output files. The first output file, SFCWEA (logical unit 10), is written in ASCII format. It may be examined by the user with the editor so that any suspicious data can be removed or replaced.

The second output file, SFCRAIN (logical unit 11), is written in binary and is also used as input into PGM-SFC2. After executing PGM-SFC1, a listing will automatically be printed that gives the year, month, day, time, and number of stations available.

```
RUN CARD          @RUN,  R/R RUNID, ETC....

                  @ASG,T  TAPENAME, U9S, TAPENUMBER
INPUT TAPE        @USE TAPEA., TAPENAME
                  @REWIND TAPEA.
                  @MOVE TAPEA., 8

PROGRAM FILE      @ASG,A PREPROC.
                  @USE A., PREPROC.

                  @ASG,PU  SFCWEA.
OUTPUT DATA       @ASG,PU  SFCRAIN.
FILES             @USE 10., SFCWEA.
                  @USE 11., SFCRAIN.

                  @XQT A.PGM-SFC1

PROGRAM           ENTER STARTING MONTH (MM), YEAR (YY), AND
EXECUTION         DAY (DD) THEN ENDING MONTH (MM) AND DAY (DD)

                  1, 80, 1, 2, 1
```

PGM-SFC2

PGM-SFC2 reads the two output files created by PGM-SFC1 (SFCWEA and SFCRAIN) and generates six output files (Table 4.5). After execution of the model, a listing of the number of relevant 6-h observations for precipitation, wind speed and direction, sky cover, stability, and mixing height will automatically be written to the printer. Also printed will be 12 x 13 arrays (corresponding to the domain used in the example execution) of the averaged gridded values of wind speed (u- and v-components, in meters per second), sky cover (in tenths), stability index (Pasquill-Gifford scale) and mixing heights (in meters) for the month of January, 1980. For this example execution, only the files containing sky cover data, SSKYE (logical unit 13) and the two wind components, SSFCU and SSFCV (logical units 11 and 12, respectively), are required by the model. The 12 x 13 arrays corresponding to these three files are presented in Appendix D. These arrays will allow the user to verify his results to ensure that his programs ran correctly.

```
FREE LOGICAL     @FREE,A  10.
UNIT NUMBERS     @FREE,A  11.

                 @ASG,PU    SRAIN.
                 @ASG,PU    SSFCU.
                 @ASG,PU    SSFCV.
                 @ASG,PU    SSKYE.
OUTPUT DATA      @ASG,PU    SSTAB.
FILES            @ASG,PU    SMIXH.
                 @USE 10.,   SRAIN.
                 @USE 11.,   SSFCU.
                 @USE 12.,   SSFCV.
                 @USE 13.,   SSKYE.
                 @USE 14.,   SSTAB.
                 @USE 15.,   SMIXH.

INPUT DATA       @USE 8.,    SFCWEA.
FILES            @USE 9.,    SFCRAIN.

                 @XQT A.PGM-SFC2

                 ENTER THE NAMES OF THE SIX OUTPUT FILES,
                 USING UP TO 28 CHARACTERS PER NAME ENCLOSED
                 IN SINGLE QUOTES

PROGRAM          'PREC DATA'
EXECUTION        'U WIND COMP'
                 'V WIND COMP'
                 'SKY COVER'
                 'STAB INDEX'
                 'MIX HGT'

                 ENTER STARTING MONTH (MM), YEAR (YY) AND DAY (DD)

                 1, 80, 1
```

PGM-TIME

The output files generated by PGM-SFC2 contain data for 6-h time periods. As is the case with this example execution, which requires a 3-h time period, the user may want to use a different time increment. This conversion is accomplished with PGM-TIME, which must be run individually for each of the data files (produced by PGM-SFC2) that are to be used as input into the model. For the example execution, this includes only the sky cover file (SSKYE) and the two wind files (SSFCU and SSFCV). With each run of PGM-TIME, logical unit 10 is assigned to the input data file, and the output data file is assigned to logical unit 11. After program execution, a message is written for every time increment that was converted successfully. Two of the output files created by PGM-TIME, LWRWNDUU-DAT and LWRWNDVV-DAT, are used as direct input into the model. The third output data file, SKY-DAT, is used as input into the program HOLEZ, which is one of the precipitation preprocessors.

```
FREE LOGICAL      @FREE,A  10.
UNIT NUMBERS      @FREE,A  11.

OUTPUT            @ASG,PU   LWRWNDUU-DAT.
DATA FILES        @USE 11.,  LWRWNDUU-DAT.

INPUT DATA        @USE 10.,  SSFCU.
FILE

                  @XQT A.PGM-TIME

                  ENTER NAME FOR OUTPUT DATA SET UP TO
                  28 CHARACTERS
PROGRAM
EXECUTION         SFC U COMP WINDS JAN, 1980

                  ENTER OLD TIME INTERVAL THEN NEW TIME INVERVAL

                  6, 3
```

```
FREE LOGICAL      @ FREE,A  10.
UNIT NUMBERS      @ FREE,A  11.

OUTPUT DATA       @ASG,PU    LWRWNDVV-DAT.
FILES             @USE 11.,   LWRWNDVV-DAT.

INPUT DATA        @USE 10.,   SSFCV.
FILE

                  @XQT   A.PGM-TIME

                  ENTER NAME FOR OUTPUT DATA SET UP TO 28
                  CHARACTERS
PROGRAM
EXECUTION         SFC V COMP WINDS  JAN, 1980

                  ENTER OLD TIME INTERVAL THEN NEW TIME
                  INTERVAL

                  6, 3

FREE LOGICAL      @FREE,A  10.
UNIT NUMBERS      @FREE,A  11.

OUTPUT DATA       @ASG,PU    SKY-DAT.
FILES             @USE  11., SKY-DAT.

INPUT DATA        @USE  10., SSKYE.
FILE

                  @XQT  A.PGM-TIME

                  ENTER NAME FOR OUTPUT DATA SET UP TO 28
                  CHARACTERS
PROGRAM
EXECUTION         SKY COVER FOR JAN, 1980

                  ENTER OLD TIME INTERVAL THEN NEW TIME INTERVAL

                  6, 3
```

PGM-RAOB

PGM-RAOB reads the tenth file of the tape, which contains the upper air data, and generates two output files: TSAVE (logical unit 10) and WSAVE (logical unit 11). TSAVE, which requires extra core space, is written in

ASCII format. This allows the user to edit the file and replace any suspicious data before the file is used as input into PGM-RAOB. The second output file (WSAVE) is written in binary and is also used as input into PGM-RAOB2. As discussed earlier, we assume in all the runstreams that the programs are run in sequence, in one session, as presented in the example execution (i.e., PGM-RAOB should be run after PGM-SFC1, PGM-SFC2, and PGM-TIME). If the user deviates from this sequence, he must first rewind the tape (@REWIND TAPEA.), and then move it to the tenth file (@MOVE TAPEA.,9) before he can proceed. After execution of PGM-RAOB, a listing of the RAOB stations used in the example execution is presented.

```
                    @ASG,PU    TSAVE., F/O/TRK/256
OUTPUT              @ASG,PU    WSAVE.
DATA FILES          @USE  10., TSAVE.
                    @USE  11., WSAVE.

                    @XQT  A.PGM-RAOB.
PROGRAM
EXECUTION           ENTER STARTING MONTH (MM), YEAR (YY) AND DAY (DD)
                    THEN ENDING MONTH (MM) AND DAY (DD)

                    1, 80, 1, 2, 1
```

PGM-RAOB2

PGM-RAOB2 reads the two files created by PGM-RAOB: TSAVE (logical unit 10) and WSAVE (logical unit 11). Then it creates five output files, as described in Section 4. Of the five files generated, only two are necessary for this example execution: R850U (logical unit 15) and R850V (logical unit 16).

After execution of PGM-RAOB2, a listing of the number of stations reporting data for surface and 850-mb winds and mixing height is automatically printed. Also printed are 12 x 13 arrays of the averaged gridded values of the mixing height and the four wind components (surface u- and v-components, and 850-mb u- and v-components) for the month of January, 1980. The 12 x 13 arrays of the 850-mb wind components are presented in Appendix D. These allow the user to verify that his results are correct.

```
INPUT DATA        @USE TGOOD., TSAVE.
FILE

                  @ASG, PU   RMIXH.
                  @ASG, PU   RSFCU.
                  @ASG, PU   RSFCV.
                  @ASG, PU   R850U.
OUTPUT            @ASG, PU   R850V.
DATA FILES        @USE 12,.  RMIXH.
                  @USE 13.,  RSFCU.
                  @USE 14.,  RSFCV.
                  @USE 15.,  R850U.
                  @USE 16.,  R850V.

                  @XQT   A.PGM-RAOB2
PROGRAM
EXECUTION         ENTER STARTING DATE IN FORMAT YYMMDDHH

                  80010100
```

PGM-TIME

The output files created by PGM-RAOB2 contain 12-h time periods, which must be converted to the 3-h time period used in the example execution by using PGM-TIME. Only the two 850-mb wind files (R850U and R850V) need to be processed through PGM-TIME, because the other data files are not required in this example. Once again, the two input files (R850U and R850V) are assigned to logical unit 10, and the two output files

(UPRWNDUU and UPRWNDVV) are assigned to logical unit 11, with each run of PGM-TIME. The output files are used directly as input into the model. After execution of the program, a message is written for every time increment that was successfully converted from 12 h to 3 h.

```
FREE INPUT       @FREE  10.
FILES FROM       @FREE  11.
RAOB2            @FREE,A 12.
                 @FREE,A 13.
FREE LOGICAL     @FREE,A 14.
UNIT NUMBERS     @FREE,A 15.
                 @FREE,A 16.

INPUT FILE       @USE  10., R850U.

OUTPUT FILE      @ASG,PU    UPRWNDUU-DAT.
                 @ASG, 11., UPRWNDUU-DAT.

                 @XQT  A.PGM-TIME

                 ENTER NAME FOR OUTPUT DATA SET UP TO 28
                 CHARACTERS
PROGRAM
EXECUTION        850 mb  U COMP WINDS JAN, 1980

                 ENTER OLD TIME INTERVAL THEN NEW TIME INTERVAL

                 12, 3

FREE             @FREE  10.
FILES            @FREE  11.

INPUT FILE       @USE  10., R850V.

OUTPUT FILE      @ASG,PU    UPRWNDVV-DAT.
                 @USE  11., UPRWNDVV-DAT.

                 @XQT  A.PGM-TIME

                 ENTER NAME FOR OUTPUT DATA SET UP TO 28
                 CHARACTERS

PROGRAM          850 mb V COMP WINDS JAN, 1980
EXECUTION

                 ENTER OLD TIME INTERVAL THEN NEW TIME INTERVAL

                 12, 3
```

WNDO-FIL

If the user wishes to run the source/receptor output version of the model, as in this example execution, he must process another data file by using WNDO-FIL, which defines the receptor regions. The source regions have already been defined in the emissions data preprocessor. Located in File 7 on the tape are 13 80-column cards that describe the receptor regions. This file should be extracted from the tape and copied to disk file in the same manner as the program files. WNDO-FIL, which requires no user input, reads this file and creates WINDOW-DAT (logical unit 11), which is used as input directly into the model. A listing depicting the receptor regions is printed out automatically with execution of the model. This listing should be read from the lower left section of the grid to the upper right hand corner.

```
                    @REWIND TAPEA
                    @MOVE TAPEA.,6

                    @FREE  10.

INPUT DATA FILE     @ASG,PU     WINDOW-DAT.

OUTPUT DATA         @ASG,PU     WINDOW-DAT.
FILE                @USE  10., WINDOW-DAT.

PROGRAM             @XQT  A.WNDO-FIL.
EXECUTION           @ADD,PL     WINDOW.
```

DEPPUFP

DEPPUFP uses a data statement to define land use categories and generates four output files that contain dry deposition velocities for SO_2, $SO_4^=$, and fine and coarse particulate matter (Table 4.13). This program, which requires no input data, provides the user with an option to define the size distribution of coarse particulate matter. Dry deposition velocities for 5-μ, 7.5-μ or 10-μ particles may be selected for input into the model.

After execution of DEPPUFP, three arrays are automatically printed. The first contains the land use categories used in the 13 x 12 grid employed by the example execution. The second array contains dry deposition velocities, by stability class and land use category, for SO_2 and $SO_4^=$, and the third array contains dry deposition velocities, by stability class and land use category, for fine and coarse particulate matter.

```
                      @ASG,PU    DRYDEP1-DAT.
                      @ASG,PU    DRYDEP2-DAT.
                      @ASG,PU    DRYDEP3-DAT.
OUTPUT DATA           @ASG,PU    DRYDEP4-DAT.
FILES                 @USE   10., DRYDEP1-DAT.
                      @USE   11., DRYDEP2-DAT.
                      @USE   12., DRYDEP3-DAT.
                      @USE   13., DRYDEP4-DAT.

                      @XQT   A.DEPPUFF

                      ENTER SEASON AS SPRING, SUMMER, AUTUMN OR WINTER

                      WINTER

PROGRAM               IS THIS DATA FOR SO2, SO4 AND PARTICULATES  Y/N
EXECUTION
                      Y

                      FOR THE LARGEST PARTICULATE SIZE:
                      IF YOU WANT TO USE 10  VELOCITIES ENTER ONE
                      IF YOU WANT TO USE 5  VELOCITIES ENTER TWO
                      IF YOU WANT TO USE AN AVERAGE OF 5  AND 10
                      ENTER A THREE

                      3
```

LOCATR

LOCATR requires no user input. It reads the twelfth file of the tape, which contains data on U.S. precipitation reporting stations. The program then creates file USWBSTA (logical unit 10), which contains all the available U.S. stations and their geographic coordinates. After execution of LOCATR, a listing of these stations and their coordinates is automatically printed.

```
PROGRAM FILE        @ASG,A    PRECIP.
                    @USE  A., PRECIP.

                    @REWIND TAPEA.
                    @MOVE TAPEA., 11

OUTPUT DATA         @ASG,PU  USWBSTA., F/O/TRK/512
FILE                @USE  10., USWBSTA.

PROGRAM             @XQT  A.LOCATR
EXECUTION
                    @REWIND TAPEA.
```

MASTER

MASTER requires the mounting of a second blank tape and creates a master tape by combining the U.S. NWS hourly precipitation file (eleventh file on the tape) with the station location file called USWBSTA (logical unit 10) created by LOCATR. This program, which requires no user input, will write the combined precipitation data to the master output tape (TAPEB). All missing data have been filled in and all times have been converted to Greenwich Mean Time. After execution, MASTER will automatically print a listing of all the station locations (latitude and longitude) for which precipitation data are available.

```
                  @ASG, TJ/W  TAPENAME, U9S, TAPENUMBER
OUTPUT TAPE       @USE TAPEB., TAPENAME
                  @REWIND TAPEB.

                  @REWIND TAPEA.
                  @MOVE TAPEA., 10

PROGRAM           @XQT  A.MASTER
EXECUTION

                  @REWIND TAPEB.
```

RTREV

RTREV retrieves only those precipitation data that pertain to the time period (January, 1980) and 12 x 13 subgrid required by the example execution from the recently created master tape. RTREV generates an ASCII format output file, JAN80RAIN (logical unit 10), that contains the precipitation data in station order. These data must be converted to chronological order. This is accomplished through a UNIVAC-specific sorting routine called SORT, which is accessed by an @ADD statement. This routine is provided with the PRECIP program file and reads the station-ordered data from JAN80RAIN to create a chronologically ordered precipitation data file called JAN80. The user must replace this UNIVAC-specific routine with a comparable routine for his system to proceed with preprocessing the precipitation data.

```
                    @FREE  TAPEA.
RENAMING MASTER     @FREE,A TAPEB.
TAPE FROM TAPEB     @USE TAPEA., MASTER
TO TAPEA            @REWIND TAPEA.,
                    @FREE 10.

OUTPUT FROM RTREV   @ASG,PU  JAN80RAIN.,F/O/TRK/512
INPUT TO SORT       @USE 10., JAN80RAIN.

                    @XQT  A.RTREV
```

```
PROGRAM              ENTER START AND THEN STOP DATES IN FORM YYMMDD
EXECUTION
                     800101    800201

OUTPUT FROM SORT     @ASG,PU  JAN80., F/O/TRK/512

PROGRAM              @ADD,PL  A.SORT
EXECUTION

                     @FREE   JAN80RAIN.
```

GRID

This program reads the file called JAN80 (logical unit 10), created by RTREV and SORT, and creates two output data files called RAINAMT (logical unit 11) and RAINCNT (logical unit 12). RAINAMT contains the total gridded precipitation amount for each time period, and RAINCNT contains the number of stations, by grid cell, contributing to the total precipitation amount. As discussed earlier, Canadian precipitation is not required by this example execution; therefore, it will not be considered.

```
INPUT DATA       @USE   10., JAN80.
FILE

                 @ASG,PU   RAINAMT.,F/O/TRK/512
OUTPUT DATA      @ASG,PU   RAINCNT.,F/O/TRK/512
FILES            @USE  11., RAINAMT.
                 @USE  12., RAINCNT.

                 @XQT  A.GRID

                 ENTER OUTPUT FILE HEADER, UP TO 28 CHARACTERS

                 US RAIN  JAN., 1980

                 ENTER TIME INCREMENT OF OUTPUT GRIDS IN HOURS

                 3
PROGRAM
EXECUTION        ENTER MULTIPLIER FACTOR TO ADJUST PREC
                 DIMENSIONS TO MILLIMETERS
```

```
25.4

ENTER A ONE IF YOU WANT TO READ IN CANADIAN
HOURLY RAIN, OTHERWISE ENTER A TWO

2

ENTER A ONE IF YOU WANT TO READ-IN CANADIAN
24-HOURLY RAIN, OTHERWISE ENTER A TWO

2
```

HOLEZ

This final preprocessor reads three input data files: RAINAMT (logical unit 11) and RAINCNT (logical unit 10), generated by GRID, and SKY-DAT (logical unit 12), generated by PGM-SFC2 and PGM-TIME. HOLEZ then creates an unformatted output file called PRECIP-DAT (logical unit 13) that contains gridded precipitation for all of the grid cells used in the example execution. This file, which contains no missing data, is used directly as input into the model. After execution of HOLEZ, the monthly total precipitation for January 1980 is automatically printed for the 12 x 13 array used in this example. This array, which is given in Appendix D, should be examined by the user to verify that he has processed the precipitation data correctly.

```
                     @FREE  10.
                     @FREE,A  12.

                     @ASG,A   SKY-DAT.
INPUT DATA           @USE 12., SKY-DAT.
FILE                 @USE 10., RAINCNT.

OUTPUT DATA          @ASG,PU  PRECIP-DAT.
FILE                 @USE  13., PRECIP-DAT.

                     @XQT  A.HOLEZ

PROGRAM              ENTER OUTPUT FILE HEADER - UP TO 28 CHARACTERS
EXECUTION

                     FINAL GRIDDED PREC JAN, 1980
```

MAIN

After preprocessing the raw input data, ten output files have been generated that will serve as input into MAIN. Table 4.15 in Section 4 lists two more files that need to be accessed by MAIN to perform the model simulations. These are INPUT-DAT, which is the fifth file on the tape, and EMISSION-DAT, which is the sixth file. INPUT-DAT is used in the subroutine DEFALT and contains all of the user-supplied input parameters required by the model (Table 4.16 in Section 4). As discussed earlier, EMISSION-DAT contains all of the preprocessed emissions data required by the example execution. Both files must be transferred from the tape to disk files with the exact names used here (i.e., INPUT-DAT, EMISSION-DAT) for the OPEN statements to work.

After execution of the model, five output files are created (Table 4.17 in Section 4) by MAIN. All of the model results are written to TEST-LIS (logical unit 31), which must be printed out by the user. Example outputs of both versions of the model (the gridded values and the source/receptor exchange tables), which are discussed in detail in Section 1, are provided. These examples allow the user to verify his final results to ensure that the model ran properly. The runstreams found below illustrate the procedure used to run both versions of the model. The first execution produces the 12 x 13 arrays of gridded values of SO_2, $SO_4^=$, fine and coarse particles, wet and dry deposition, and concentration (Figure 5.3). The second execution, which requires slight modification of INPUT-DAT as shown, produces the source/receptor simulations (Figure 5.4). A total of 6 source regions and 19 receptor regions were arbitrarily selected for the source/receptor example execution (Figures 5.5 and 5.6).

```
PROGRAM FILE      @ASG,A  RELMAP.
                  @USE    A.,RELMAP.

PROGRAM           @XQT   A.MAIN
EXECUTION

PRINT OUTPUT      @SYM,U  TEST-LIS.,,FD04PR
```

To execute the model in the source/receptor mode, the user must edit the file INPUT-DAT, and change the following parameters: FMATRIX and FWINDO must be changed from .FALSE. to .TRUE., and NREG must be changed from 1 to 19. The runstream shown above is also used to execute this simulation.

```
                                               SULFUR BUDGET (KILOTONNES)
             INPUT         WET-DEPOSIT      DRY-DEPOSIT      LEFT GRID      REMAIN IN PUFFS      TRANSFORMED

 SO2        689.422          10.064           26.191          552.374           26.011              74.712
 SO4         11.463           3.093            3.914           75.775            3.399
                                               PARTICULATE BUDGET (KILOTONNES)
             INPUT         WET-DEPOSIT      DRY-DEPOSIT      LEFT GRID      REMAIN IN PUFFS

 P25        244.275           9.573            8.968          216.077            9.635
 P10        168.222           6.348           22.990          132.897            5.999
                                              SO2  WET-DEPOSITION     KG/HA
                       JANUARY    1980

       1      2      3      4      5      6      7      8      9     10     11     12
13    .01    .01    .03    .06    .09    .05    .08    .03    .08    .18    .17    .10
12    .00    .01    .03    .02    .09    .08    .08    .07    .08    .06    .23    .17
11    .00    .01    .04    .04    .05    .07    .07    .07    .17    .23    .35    .22
10    .00    .02    .04    .05    .07    .11    .15    .16    .22    .35    .41    .38
 9    .00    .03    .03    .06    .16    .19    .28    .21    .28    .30    .58    .54
 8    .00    .00    .03    .10    .21    .29    .20    .33    .27    .40    .65    .31
 7    .00    .01    .05    .07    .13    .17    .34    .37    .38    .36    .34    .25
 6    .00    .01    .03    .03    .07    .25    .20    .26    .49    .27    .14    .20
 5    .00    .00    .02    .01    .06    .16    .27    .34    .45    .25    .25    .21
 4    .00    .01    .03    .04    .05    .12    .28    .22    .24    .15    .17    .18
 3    .00    .01    .04    .07    .09    .10    .08    .07    .07    .17    .08    .05
 2    .00    .06    .06    .08    .10    .12    .05    .05    .06    .04    .12    .08
 1    .00           .02    .04           .04    .04    .00    .02    .02           .05
                                              SO4  WET-DEPOSITION     KG/HA
                       JANUARY    1980

       1      2      3      4      5      6      7      8      9     10     11     12
13    .00    .00    .01    .02    .03    .01    .02    .01    .03    .08    .08    .03
12    .00    .00    .01    .00    .02    .02    .03    .02    .03    .02    .09    .05
11    .00    .00    .01    .01    .01    .02    .02    .04    .07    .12    .17    .09
10    .00    .00    .01    .02    .02    .04    .06    .07    .12    .21    .24    .19
 9    .00    .01    .01    .02    .06    .07    .11    .10    .13    .18    .33    .25
 8    .00    .00    .01    .03    .09    .12    .11    .18    .16    .23    .38    .19
 7    .00    .00    .02    .04    .04    .05    .14    .16    .18    .20    .20    .15
 6    .00    .00    .01    .01    .02    .10    .09    .11    .25    .18    .09    .12
 5    .00    .00    .01    .01    .02    .04    .11    .13    .20    .13    .13    .14
 4    .00    .00    .01    .01    .02    .04    .10    .07    .09    .06    .08    .11
 3    .00    .00    .01    .02    .03    .03    .03    .03    .03    .10    .05    .02
 2    .00    .01    .01    .02    .02    .04    .02    .02    .02    .02    .10    .04
 1    .00    .00    .00    .01           .01    .01    .00    .00    .01           .02
```

Figure 5.3. Gridded values from example execution output results.

```
                                                      SLFR WET-DEPOSITION    KG/HA
                                  JANUARY   1980

           1        2        3        4        5        6        7        8        9       10       11       12
  13      .00      .01      .02      .04      .05      .03      .05      .02      .05      .11      .11      .06
  12      .00      .01      .02      .01      .06      .05      .05      .04      .05      .04      .14      .10
  11      .00      .00      .02      .02      .03      .04      .04      .05      .11      .16      .23      .14
  10      .00      .01      .02      .03      .04      .07      .10      .10      .15      .24      .29      .26
   9      .00      .02      .02      .04      .10      .12      .18      .14      .18      .21      .40      .36
   8      .00      .00      .02      .06      .13      .18      .14      .22      .19      .28      .45      .22
   7      .00      .00      .03      .05      .08      .10      .22      .24      .25      .25      .24      .18
   6      .00      .01      .02      .02      .04      .16      .13      .17      .33      .20      .10      .14
   5      .00      .00      .01      .01      .03      .09      .17      .21      .29      .17      .17      .15
   4      .00      .01      .02      .02      .03      .07      .17      .14      .15      .10      .11      .13
   3      .00      .01      .03      .04      .05      .06      .05      .05      .05      .12      .06      .03
   2      .00      .03      .03      .04      .06      .07      .03      .03      .03      .02      .09      .05
   1      .00      .00      .01      .02               .02      .02      .00      .01      .01               .03
                                                      P25  WET-DEPOSITION    KG/HA
                                  JANUARY   1980

           1        2        3        4        5        6        7        8        9       10       11       12
  13      .01      .01      .02      .02      .04      .03      .03      .01      .03      .08      .08      .04
  12      .00      .01      .02      .01      .05      .04      .04      .02      .04      .03      .10      .06
  11      .00      .01      .02      .02      .02      .03      .03      .04      .07      .09      .11      .07
  10      .00      .01      .01      .02      .02      .05      .06      .07      .08      .13      .15      .12
   9      .00      .02      .01      .02      .05      .05      .07      .07      .11      .11      .20      .15
   8      .00      .01      .02      .03      .06      .07      .05      .09      .11      .18      .25      .13
   7      .00      .01      .03      .03      .04      .08      .14      .14      .17      .16      .16      .14
   6      .00      .01      .03      .05      .05      .13      .12      .13      .19      .14      .12      .14
   5      .00      .01      .03      .03      .05      .08      .14      .14      .21      .18      .19      .14
   4      .00      .02      .04      .05      .04      .06      .13      .11      .18      .12      .15      .12
   3      .00      .01      .03      .05      .05      .05      .05      .05      .06      .09      .08      .04
   2      .00      .02      .03      .04      .04      .06      .03      .04      .05      .04      .10      .07
   1      .00      .00      .01      .02               .02      .03      .00      .01      .02               .05
                                                      P10  WET-DEPOSITION    KG/HA
                                  JANUARY   1980

           1        2        3        4        5        6        7        8        9       10       11       12
  13      .01      .01      .02      .02      .03      .02      .02      .01      .02      .04      .04      .02
  12      .00      .01      .02      .01      .03      .03      .02      .01      .02      .01      .05      .03
  11      .00      .01      .02      .01      .02      .02      .02      .02      .04      .05      .06      .05
  10      .01      .01      .01      .01      .02      .03      .03      .03      .04      .07      .08      .07
   9      .00      .02      .01      .02      .04      .04      .04      .03      .05      .06      .12      .10
   8      .00      .01      .02      .03      .04      .05      .04      .05      .06      .10      .15      .08
   7      .01      .01      .03      .03      .04      .06      .10      .10      .11      .11      .10      .08
   6      .00      .02      .03      .05      .05      .12      .09      .09      .12      .08      .07      .09
   5      .00      .01      .03      .04      .05      .07      .10      .09      .13      .11      .12      .09
   4      .00      .02      .03      .05      .04      .04      .08      .06      .11      .08      .10      .08
   3      .00      .01      .02      .03      .03      .03      .03      .03      .04      .06      .05      .03
   2      .00      .01      .02      .02      .02      .03      .02      .03      .03      .03      .06      .04
   1      .00      .00      .00      .01               .01      .02      .00      .01      .01               .02
```

Figure 5.3. Continued.

SO2 DRY-DEPOSITION KG/HA

JANUARY 1980

	1	2	3	4	5	6	7	8	9	10	11	12
13	.00	.02	.05	.09	.10	.09	.12	.16	.18	.26	.19	.22
12	.01	.06	.10	.19	.05	.20	.35	.36	.42	.48	.49	.39
11	.02	.08	.14	.15	.27	.37	.46	.43	.48	.54	.66	.53
10	.04	.10	.16	.23	.35	.45	.52	.55	.63	.72	.74	.57
9	.05	.12	.24	.45	.55	.59	.71	.70	.74	.80	1.03	.86
8	.08	.16	.24	.36	.49	.64	.70	.77	.72	.91	1.09	.74
7	.01	.05	.17	.26	.39	.54	.73	.87	.92	.75	.82	.67
6	.00	.01	.08	.18	.28	.44	.66	.70	.73	.80	.68	.58
5	.00	.01	.05	.11	.13	.27	.45	.61	.66	.70	.62	.46
4	.00	.01	.03	.06	.09	.22	.35	.45	.54	.56	.55	.37
3	.00	.02	.03	.09	.11	.17	.25	.32	.36	.39	.40	.29
2	.01	.02	.06	.13	.16	.17	.18	.21	.24	.33	.54	.25
1	.01	.01	.08	.19	.19	.18	.16	.16	.20	.24	.26	.24

SO4 DRY-DEPOSITION KG/HA

JANUARY 1980

	1	2	3	4	5	6	7	8	9	10	11	12
13	.00	.00	.01	.01	.01	.01	.02	.03	.04	.06	.02	.05
12	.00	.01	.01	.02	.03	.03	.05	.06	.08	.09	.10	.07
11	.00	.01	.03	.03	.04	.05	.07	.08	.10	.13	.14	.10
10	.01	.02	.03	.04	.05	.08	.10	.11	.13	.17	.17	.12
9	.01	.02	.04	.07	.09	.11	.13	.13	.15	.19	.27	.21
8	.02	.03	.04	.06	.09	.11	.14	.15	.16	.21	.27	.18
7	.01	.01	.03	.05	.07	.10	.14	.19	.21	.20	.25	.19
6	.00	.00	.02	.03	.05	.09	.14	.16	.19	.22	.21	.17
5	.00	.00	.01	.02	.03	.06	.10	.15	.17	.19	.19	.14
4	.00	.00	.01	.01	.02	.05	.07	.11	.15	.16	.16	.12
3	.00	.00	.00	.01	.02	.03	.06	.08	.10	.12	.12	.09
2	.00	.00	.01	.02	.02	.03	.04	.06	.07	.11	.13	.04
1	.00	.00	.01	.02	.02	.03	.03	.04	.06	.09	.11	.04

SLFR DRY-DEPOSITION KG/HA

JANUARY 1980

	1	2	3	4	5	6	7	8	9	10	11	12
13	.00	.01	.03	.05	.05	.05	.07	.09	.10	.15	.10	.13
12	.01	.03	.05	.10	.04	.11	.19	.20	.24	.27	.28	.22
11	.01	.04	.08	.08	.15	.20	.26	.24	.28	.31	.38	.30
10	.03	.06	.09	.13	.19	.26	.29	.31	.36	.42	.43	.33
9	.03	.07	.13	.25	.30	.33	.40	.39	.42	.46	.61	.50
8	.04	.09	.13	.20	.27	.36	.39	.43	.41	.53	.63	.43
7	.01	.03	.09	.14	.22	.30	.41	.49	.53	.44	.49	.40
6	.00	.01	.04	.10	.16	.25	.37	.40	.43	.48	.41	.35
5	.00	.01	.03	.06	.07	.16	.26	.36	.39	.41	.37	.28
4	.00	.01	.02	.03	.05	.13	.20	.26	.32	.33	.33	.22
3	.00	.01	.02	.05	.06	.10	.15	.19	.22	.23	.24	.18
2	.00	.01	.03	.07	.09	.09	.10	.12	.15	.20	.31	.14
1	.01	.01	.05	.10	.10	.10	.09	.10	.12	.15	.17	.13

Figure 5.3. Continued.

P25 DRY-DEPOSITION KG/HA

JANUARY 1980

	1	2	3	4	5	6	7	8	9	10	11	12
13	.00	.01	.01	.02	.01	.01	.03	.03	.03	.04	.02	.03
12	.01	.01	.02	.03	.05	.04	.05	.06	.08	.09	.08	.06
11	.01	.02	.03	.03	.04	.06	.08	.08	.10	.10	.10	.08
10	.01	.02	.03	.04	.05	.06	.08	.09	.10	.11	.11	.09
9	.01	.02	.04	.06	.06	.07	.08	.09	.10	.12	.15	.10
8	.02	.04	.05	.05	.07	.07	.09	.09	.09	.12	.14	.09
7	.01	.02	.04	.05	.06	.07	.09	.11	.12	.11	.13	.10
6	.00	.02	.03	.05	.06	.07	.10	.10	.11	.11	.11	.09
5	.00	.01	.02	.04	.04	.06	.07	.10	.10	.10	.10	.08
4	.00	.01	.02	.03	.04	.05	.06	.08	.10	.09	.09	.08
3	.00	.01	.02	.03	.04	.05	.06	.07	.07	.08	.08	.07
2	.00	.01	.02	.03	.04	.04	.05	.06	.07	.09	.09	.03
1	.00	.00	.02	.04	.04	.05	.05	.06	.07	.08	.09	.03

P10 DRY-DEPOSITION KG/HA

JANUARY 1980

	1	2	3	4	5	6	7	8	9	10	11	12
13	.01	.02	.03	.05	.05	.06	.05	.06	.06	.07	.07	.06
12	.03	.04	.05	.09	.17	.08	.11	.12	.14	.15	.17	.11
11	.03	.04	.07	.08	.10	.12	.14	.15	.17	.18	.18	.14
10	.04	.05	.08	.09	.12	.14	.16	.17	.18	.19	.19	.16
9	.04	.08	.14	.18	.17	.17	.20	.20	.20	.21	.37	.18
8	.09	.19	.17	.18	.21	.20	.22	.20	.17	.35	.35	.16
7	.06	.09	.16	.19	.20	.21	.23	.39	.35	.20	.39	.18
6	.02	.06	.12	.17	.29	.21	.41	.34	.32	.34	.22	.18
5	.01	.04	.09	.14	.14	.16	.19	.36	.34	.21	.22	.16
4	.01	.03	.06	.11	.13	.16	.17	.20	.22	.21	.21	.17
3	.01	.02	.05	.08	.10	.12	.15	.16	.16	.17	.18	.15
2	.01	.01	.04	.12	.14	.09	.11	.14	.16	.29	.16	.13
1	.01	.02	.07	.13	.09	.15	.17	.22	.17	.29	.25	.13

SO2 CONCENTRATION UG/M3

JANUARY 1980

	1	2	3	4	5	6	7	8	9	10	11	12
13	.28	.72	1.42	2.32	3.33	3.95	5.00	5.92	6.34	7.50	6.56	6.33
12	.59	1.70	4.26	7.72	9.11	10.21	12.56	12.24	13.83	13.64	16.79	13.06
11	.81	2.96	5.75	7.96	12.10	15.00	15.01	13.99	14.45	15.20	20.89	16.34
10	.99	2.95	5.39	8.42	12.83	14.97	17.72	16.68	17.56	20.60	20.35	19.30
9	1.41	5.30	10.42	16.25	19.64	22.85	23.42	21.82	23.16	24.86	24.90	24.03
8	.97	4.11	9.25	12.82	16.62	22.01	22.63	24.51	22.64	21.76	24.10	20.14
7	.24	1.44	5.21	8.63	13.72	19.95	23.57	22.03	21.97	18.34	17.19	16.30
6	.05	.69	2.97	5.81	7.37	14.07	16.60	17.54	17.19	16.30	14.86	13.47
5	.15	.57	2.06	3.33	4.91	9.00	12.53	15.32	16.38	15.37	13.92	10.53
4	.09	.50	1.31	2.20	3.64	6.98	11.00	13.54	14.25	13.43	11.91	8.45
3	.15	.80	1.56	2.98	4.12	5.61	7.92	9.77	10.20	9.67	8.84	7.12
2	.30	1.13	3.22	4.87	5.30	5.27	5.08	5.83	6.53	6.80	8.30	7.03
1	.49	1.60	4.89	7.90	7.48	5.98	4.14	4.86	5.21	5.12	6.21	6.63

Figure 5.3. Continued.

```
                                                       SO4  CONCENTRATION UG/M3
                         JANUARY   1980

        1      2      3      4      5      6      7      8      9     10     11     12
 13   .04    .12    .20    .31    .46    .59    .77    .90   1.02   1.32   1.21   1.05
 12   .07    .23    .51    .90   1.05   1.24   1.71   1.80   2.11   2.38   2.74   1.94
 11   .12    .44    .83   1.06   1.55   1.91   2.15   2.11   2.54   3.00   3.60   2.62
 10   .20    .49    .83   1.25   1.75   2.29   2.71   2.80   3.27   3.92   3.84   3.19
  9   .28    .77   1.39   2.30   2.78   3.29   3.61   3.56   3.95   4.62   4.87   4.46
  8   .25    .71   1.35   1.88   2.61   3.31   3.78   4.11   4.08   4.34   4.94   4.13
  7   .07    .31    .83   1.35   2.13   2.95   3.77   4.07   4.31   4.27   4.28   3.96
  6   .01    .13    .49    .99   1.27   2.37   2.98   3.38   3.68   3.89   3.91   3.34
  5   .02    .09    .32    .66    .90   1.64   2.41   3.06   3.36   3.61   3.57   2.73
  4   .02    .09    .23    .40    .69   1.30   2.01   2.58   3.05   3.12   3.14   2.36
  3   .02    .12    .22    .45    .70   1.02   1.53   1.96   2.25   2.39   2.48   2.05
  2   .03    .14    .36    .56    .71    .86   1.02   1.38   1.63   1.91   2.37   2.05
  1   .06    .16    .49    .81    .85    .77    .79    .98   1.22   1.43   1.65   1.76
```

```
                                                       SLFR CONCENTRATION UG/M3
                         JANUARY   1980

        1      2      3      4      5      6      7      8      9     10     11     12
 13   .15    .40    .77   1.27   1.82   2.17   2.75   3.26   3.51   4.19   3.68   3.51
 12   .32    .92   2.30   4.16   4.90   5.52   6.85   6.72   7.62   7.61   9.31   7.18
 11   .45   1.62   3.15   4.33   6.57   8.14   8.22   7.70   8.07   8.60  11.64   9.04
 10   .56   1.64   2.97   4.63   7.00   8.25   9.77   9.27   9.87  11.61  11.46  10.71
  9   .80   2.91   5.67   8.89  10.75  12.52  12.91  12.10  12.90  13.97  14.07  13.50
  8   .57   2.29   5.07   7.04   9.18  12.11  12.57  13.63  12.68  12.33  13.70  11.45
  7   .14    .82   2.88   4.77   7.57  10.96  13.04  12.37  12.42  10.59  10.02   9.47
  6   .03    .39   1.65   3.23   4.11   7.83   9.29   9.90   9.82   9.45   8.74   7.85
  5   .08    .32   1.14   1.83   2.75   5.05   7.07   8.68   9.31   8.89   8.15   6.18
  4   .05    .28    .73   1.23   2.05   3.92   6.17   7.63   8.14   7.76   7.00   5.01
  3   .08    .44    .85   1.64   2.29   3.15   4.47   5.54   5.85   5.63   5.25   4.24
  2   .16    .61   1.73   2.62   2.89   2.92   2.88   3.37   3.81   4.04   4.94   4.20
  1   .26    .85   2.61   4.22   4.02   3.24   2.33   2.76   3.01   3.04   3.66   3.90
```

```
                                                       P25  CONCENTRATION UG/M3
                         JANUARY   1980

        1      2      3      4      5      6      7      8      9     10     11     12
 13   .14    .28    .45    .58    .66    .98   1.07   1.35   1.43   1.83   1.89   1.45
 12   .29    .58   1.01   1.58   1.84   2.01   2.39   2.36   3.15   3.21   3.48   2.65
 11   .30    .74   1.30   1.69   2.16   2.89   3.13   2.78   3.12   3.00   3.36   2.78
 10   .34    .75   1.06   1.46   1.83   2.27   2.69   3.13   3.32   3.56   3.48   2.87
  9   .46   1.34   2.07   2.43   2.59   2.64   2.80   2.98   3.29   3.72   3.64   3.06
  8   .41   1.35   2.30   2.33   2.39   2.29   2.51   2.66   2.72   2.96   3.19   2.79
  7   .27    .94   1.73   2.08   2.31   2.44   2.73   2.76   2.96   2.92   3.09   2.78
  6   .17    .68   1.35   1.85   2.00   2.31   2.67   2.62   2.80   2.78   2.90   2.67
  5   .14    .53   1.10   1.61   1.76   1.97   2.30   2.63   2.89   2.98   2.97   2.45
  4   .10    .44    .89   1.37   1.60   1.90   2.27   2.71   3.10   2.94   2.93   2.44
  3   .10    .41    .85   1.26   1.45   1.65   1.87   2.37   2.47   2.76   2.66   2.27
  2   .10    .37    .99   1.43   1.48   1.48   1.53   1.89   2.14   2.44   2.81   2.29
  1   .11    .39   1.23   1.77   1.67   1.47   1.37   1.74   2.22   2.04   2.45   2.48
```

Figure 5.3. Continued.

```
                                                            P10  CONCENTRATION UG/M3
                                  JANUARY   1980

         1        2        3        4        5        6        7        8        9       10       11       12
 13     .16      .29      .43      .50      .52      .61      .55      .59      .62      .76      .84      .67
 12     .30      .58      .88     1.12     1.05     1.09     1.13     1.11     1.38     1.30     1.59     1.19
 11     .30      .67     1.04     1.15     1.26     1.50     1.42     1.19     1.32     1.37     1.55     1.43
 10     .35      .71      .93     1.07     1.18     1.29     1.33     1.29     1.35     1.48     1.62     1.51
  9     .48     1.40     2.04     2.09     1.95     1.76     1.56     1.43     1.42     1.57     1.69     1.62
  8     .42     1.42     2.30     2.07     1.92     1.61     1.59     1.46     1.30     1.34     1.53     1.46
  7     .30     1.06     1.81     2.03     1.96     1.82     1.82     1.65     1.55     1.50     1.58     1.48
  6     .19      .79     1.42     1.71     1.61     1.72     1.72     1.56     1.54     1.48     1.56     1.46
  5     .15      .56     1.10     1.42     1.44     1.46     1.47     1.52     1.63     1.67     1.66     1.38
  4     .11      .43      .85     1.23     1.32     1.36     1.44     1.56     1.77     1.71     1.67     1.37
  3     .09      .36      .74     1.02     1.09     1.11     1.17     1.33     1.40     1.54     1.51     1.31
  2     .08      .28      .66      .89      .91      .88      .92     1.12     1.27     1.39     1.53     1.25
  1     .07      .24      .68      .95      .93      .83      .82     1.10     1.39     1.29     1.35     1.20
```

Figure 5.3. Continued.

```
                                   SULFUR BUDGET (KILOTONNES)
           INPUT      WET-DEPOSIT      DRY-DEPOSIT      LEFT GRID      REMAIN IN PUFFS      TRANSFORMED
S02      689.422           10.064           26.191        552.374               26.011
S04       11.463            3.093            3.914         75.775                3.399           74.712
                                 PARTICULATE BUDGET (KILOTONNES)
           INPUT      WET-DEPOSIT      DRY-DEPOSIT      LEFT GRID      REMAIN IN PUFFS
P25      244.275            9.573            8.968        216.077                9.635
P10      168.222            6.348           22.990        132.897                5.999
                                 EMITTING REGION NUMBER  1
                         JANUARY   1980

          S02      S02      S02      S04      S04      S04     SLFR     SLFR     SLFR      P25      P25      P25      P10      P10      P10
REC   WET-DEP  DRY-DEP     CONC  WET-DEP  DRY-DEP     CONC  WET-DEP  DRY-DEP     CONC  WET-DEP  DRY-DEP     CONC  WET-DEP  DRY-DEP     CONC
NO      KG/HA    KG/HA    UG/M3    KG/HA    KG/HA    UG/M3    KG/HA    KG/HA    UG/M3    KG/HA    KG/HA    UG/M3    KG/HA    KG/HA    UG/M3
  1       .00      .00      .00      .00      .00      .00      .00      .00      .00      .00      .00      .00      .00      .00      .00
  2       .00      .00      .08      .00      .00      .01      .00      .00      .04      .00      .00      .01      .00      .00      .01
  3       .00      .02      .47      .00      .00      .10      .00      .01      .27      .00      .00      .05      .00      .01      .04
  4       .00      .01      .14      .00      .00      .05      .00      .01      .08      .00      .00      .01      .00      .01      .01
  5       .01      .06      .93      .01      .02      .29      .01      .04      .56      .00      .00      .07      .00      .01      .05
  6       .00      .00      .02      .00      .00      .00      .00      .00      .01      .00      .00      .00      .00      .00      .00
  7       .03      .14     3.91      .01      .03      .69      .02      .08     2.18      .00      .01      .25      .00      .03      .19
  8       .10      .20     8.10      .04      .03     1.04      .06      .11     4.40      .01      .01      .49      .01      .02      .28
  9       .04      .20     4.34      .03      .05     1.02      .03      .12     2.51      .01      .01      .24      .00      .02      .12
 10       .24      .35    11.74      .09      .07     1.68      .15      .20     6.43      .03      .02      .65      .03      .05      .48
 11       .01      .01      .23      .00      .00      .03      .00      .00      .12      .00      .00      .03      .00      .00      .03
 12       .01      .01      .50      .00      .00      .07      .00      .01      .27      .00      .00      .05      .00      .00      .06
 13       .00      .00      .00      .00      .00      .00      .00      .00      .00      .00      .00      .00      .00      .00      .00
 14       .00      .00      .04      .00      .00      .01      .00      .00      .03      .00      .00      .01      .00      .00      .01
 15       .03      .05     1.84      .01      .01      .25      .02      .03     1.00      .00      .00      .11      .00      .01      .07
 16       .02      .02      .93      .01      .01      .19      .01      .01      .53      .00      .00      .06      .00      .00      .03
 17       .08      .14     4.26      .03      .03      .68      .05      .08     2.35      .01      .01      .25      .01      .02      .15
 18       .08      .13     4.51      .02      .02      .61      .05      .07     2.46      .01      .01      .28      .01      .01      .22
 19       .04      .04     1.52      .03      .01      .37      .03      .02      .68      .01      .00      .10      .00      .01      .06
                                 EMITTING REGION NUMBER  2
                         JANUARY   1980

          S02      S02      S02      S04      S04      S04     SLFR     SLFR     SLFR      P25      P25      P25      P10      P10      P10
REC   WET-DEP  DRY-DEP     CONC  WET-DEP  DRY-DEP     CONC  WET-DEP  DRY-DEP     CONC  WET-DEP  DRY-DEP     CONC  WET-DEP  DRY-DEP     CONC
NO      KG/HA    KG/HA    UG/M3    KG/HA    KG/HA    UG/M3    KG/HA    KG/HA    UG/M3    KG/HA    KG/HA    UG/M3    KG/HA    KG/HA    UG/M3
  1       .00      .00      .00      .00      .00      .00      .00      .00      .00      .00      .00      .00      .00      .00      .00
  2       .00      .00      .00      .00      .00      .00      .00      .00      .00      .00      .00      .00      .00      .00      .00
  3       .00      .00      .02      .00      .00      .02      .00      .00      .02      .00      .00      .01      .00      .00      .00
  4       .00      .00      .03      .00      .00      .03      .00      .00      .02      .00      .00      .01      .00      .00      .00
  5       .00      .01      .11      .00      .01      .09      .00      .01      .08      .00      .00      .03      .00      .00      .01
  6       .00      .00      .00      .00      .00      .00      .00      .00      .00      .00      .00      .00      .00      .00      .00
  7       .00      .02      .22      .00      .01      .12      .00      .01      .15      .00      .00      .06      .00      .01      .01
  8       .02      .07     1.05      .01      .02      .34      .01      .04      .64      .01      .01      .23      .00      .02      .07
  9       .00      .05      .51      .01      .02      .26      .00      .03      .34      .00      .01      .12      .00      .01      .03
 10       .05      .14     2.35      .05      .05      .72      .04      .09     1.41      .03      .03      .54      .01      .04      .16
 11       .00      .00      .05      .00      .00      .02      .00      .00      .03      .00      .00      .01      .00      .00      .00
 12       .00      .04     1.19      .00      .01      .24      .00      .02      .68      .00      .01      .22      .00      .01      .08
 13       .00      .00      .01      .00      .00      .00      .00      .00      .01      .00      .00      .01      .00      .00      .00
 14       .01      .01      .25      .00      .00      .04      .00      .01      .14      .00      .00      .07      .00      .00      .02
 15       .02      .12     4.87      .01      .02      .70      .01      .07     2.67      .01      .02      .98      .00      .03      .39
 16       .02      .07     3.06      .01      .01      .44      .01      .04     1.68      .01      .02      .87      .01      .02      .34
 17       .04      .19     6.27      .02      .04     1.11      .03      .11     3.50      .02      .04     1.46      .01      .05      .51
 18       .03      .17     6.83      .01      .03      .96      .02      .10     3.73      .02      .03     1.57      .01      .05      .59
 19       .05      .07     3.08      .01      .01      .43      .03      .04     1.68      .03      .01     1.21      .01      .03      .47
```

Figure 5.4. Source/receptor matrices from example execution output results.

```
                                            EMITTING REGION NUMBER  3
                        JANUARY   1980
         SO2     SO2      SO2     SO4     SO4      SO4     SLFR    SLFR    SLFR    P25     P25     P25     P10     P10     P10
REC  WET-DEP DRY-DEP    CONC  WET-DEP DRY-DEP    CONC  WET-DEP DRY-DEP    CONC  WET-DEP DRY-DEP    CONC  WET-DEP DRY-DEP    CONC
 NO    KG/HA   KG/HA   UG/M3    KG/HA   KG/HA   UG/M3    KG/HA   KG/HA   UG/M3    KG/HA   KG/HA   UG/M3    KG/HA   KG/HA   UG/M3
  1      .00     .01     .60      .00     .00     .06      .00     .00     .32      .00     .00     .15      .00     .01     .10
  2      .03     .05    2.19      .01     .01     .27      .02     .03    1.18      .02     .02     .70      .02     .05     .48
  3      .05     .08    2.31      .02     .01     .39      .03     .05    1.28      .03     .02     .66      .02     .05     .37
  4      .02     .08    2.00      .00     .02     .34      .01     .05    1.11      .01     .02     .54      .00     .07     .29
  5      .04     .05    1.01      .02     .02     .30      .03     .03     .60      .02     .02     .32      .01     .03     .15
  6      .00     .00     .11      .00     .00     .02      .00     .00     .06      .00     .00     .06      .00     .00     .06
  7      .02     .03     .58      .01     .01     .14      .02     .02     .34      .02     .01     .25      .01     .02     .14
  8      .01     .01     .19      .01     .00     .05      .01     .00     .11      .01     .00     .08      .00     .01     .05
  9      .02     .02     .28      .01     .01     .09      .01     .01     .17      .01     .01     .11      .01     .01     .05
 10      .01     .01     .09      .01     .00     .03      .01     .00     .05      .01     .00     .04      .00     .00     .02
 11      .00     .00     .11      .00     .00     .01      .00     .00     .06      .00     .00     .04      .00     .00     .04
 12      .00     .00     .09      .00     .00     .01      .00     .00     .05      .00     .00     .04      .00     .00     .03
 13      .00     .00     .00      .00     .00     .00      .00     .00     .00      .00     .00     .00      .00     .00     .00
 14      .00     .00     .01      .00     .00     .00      .00     .00     .01      .00     .00     .00      .00     .00     .00
 15      .00     .00     .09      .00     .00     .02      .00     .00     .05      .00     .00     .05      .00     .01     .03
 16      .00     .00     .02      .00     .00     .01      .00     .00     .01      .00     .00     .01      .00     .00     .01
 17      .01     .00     .09      .01     .00     .03      .01     .00     .06      .01     .00     .04      .00     .00     .02
 18      .01     .01     .07      .01     .00     .02      .01     .00     .04      .01     .00     .02      .00     .00     .01
 19      .01     .00     .03      .01     .00     .01      .01     .00     .02      .01     .00     .02      .00     .00     .01
                                            EMITTING REGION NUMBER  4
                        JANUARY   1980
         SO2     SO2      SO2     SO4     SO4      SO4     SLFR    SLFR    SLFR    P25     P25     P25     P10     P10     P10
REC  WET-DEP DRY-DEP    CONC  WET-DEP DRY-DEP    CONC  WET-DEP DRY-DEP    CONC  WET-DEP DRY-DEP    CONC  WET-DEP DRY-DEP    CONC
 NO    KG/HA   KG/HA   UG/M3    KG/HA   KG/HA   UG/M3    KG/HA   KG/HA   UG/M3    KG/HA   KG/HA   UG/M3    KG/HA   KG/HA   UG/M3
  1      .00     .00     .00      .00     .00     .00      .00     .00     .00      .00     .00     .00      .00     .00     .00
  2      .00     .00     .00      .00     .00     .00      .00     .00     .00      .00     .00     .00      .00     .00     .00
  3      .00     .00     .00      .00     .00     .00      .00     .00     .00      .00     .00     .00      .00     .00     .00
  4      .00     .00     .30      .00     .00     .03      .00     .00     .16      .00     .00     .12      .00     .00     .04
  5      .00     .01     .20      .00     .00     .03      .00     .00     .11      .00     .00     .08      .00     .00     .03
  6      .00     .00     .00      .00     .00     .00      .00     .00     .00      .00     .00     .00      .00     .00     .00
  7      .00     .00     .14      .00     .00     .02      .00     .00     .08      .00     .00     .06      .00     .00     .04
  8      .00     .00     .00      .00     .00     .00      .00     .00     .00      .00     .00     .00      .00     .00     .00
  9      .01     .00     .08      .00     .00     .01      .00     .00     .04      .01     .00     .02      .00     .00     .02
 10      .00     .00     .01      .00     .00     .00      .00     .00     .01      .00     .00     .00      .00     .00     .00
 11      .00     .00     .00      .00     .00     .00      .00     .00     .00      .00     .00     .00      .00     .00     .00
 12      .00     .00     .00      .00     .00     .00      .00     .00     .00      .00     .00     .00      .00     .00     .00
 13      .00     .00     .00      .00     .00     .00      .00     .00     .00      .00     .00     .00      .00     .00     .00
 14      .00     .00     .00      .00     .00     .00      .00     .00     .00      .00     .00     .00      .00     .00     .00
 15      .00     .00     .00      .00     .00     .00      .00     .00     .00      .00     .00     .00      .00     .00     .00
 16      .00     .00     .00      .00     .00     .00      .00     .00     .00      .00     .00     .00      .00     .00     .00
 17      .00     .00     .00      .00     .00     .00      .00     .00     .00      .00     .00     .00      .00     .00     .00
 18      .00     .00     .00      .00     .00     .00      .00     .00     .00      .00     .00     .00      .00     .00     .00
 19      .00     .00     .00      .00     .00     .00      .00     .00     .00      .00     .00     .00      .00     .00     .00
```

Figure 5.4. Continued.

EMITTING REGION NUMBER 5

JANUARY 1980

REC NO	SO2 WET-DEP KG/HA	SO2 DRY-DEP KG/HA	SO2 CONC UG/M3	SO4 WET-DEP KG/HA	SO4 DRY-DEP KG/HA	SO4 CONC UG/M3	SLFR WET-DEP KG/HA	SLFR DRY-DEP KG/HA	SLFR CONC UG/M3	P25 WET-DEP KG/HA	P25 DRY-DEP KG/HA	P25 CONC UG/M3	P10 WET-DEP KG/HA	P10 DRY-DEP KG/HA	P10 CONC UG/M3
1	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
2	.00	.00	.07	.00	.00	.02	.00	.00	.04	.00	.00	.02	.00	.00	.01
3	.00	.02	.36	.00	.01	.12	.00	.01	.22	.00	.00	.08	.00	.01	.05
4	.00	.01	.12	.00	.01	.06	.00	.01	.08	.00	.00	.03	.00	.01	.02
5	.00	.04	.49	.00	.02	.20	.00	.03	.31	.00	.01	.11	.00	.02	.07
6	.00	.00	.05	.00	.00	.02	.00	.00	.03	.00	.00	.02	.00	.01	.02
7	.01	.07	1.31	.01	.02	.37	.01	.04	.78	.00	.01	.27	.00	.04	.19
8	.02	.12	2.93	.01	.03	.63	.01	.07	1.67	.01	.02	.57	.01	.07	.43
9	.01	.07	.98	.01	.03	.39	.01	.04	.62	.01	.01	.22	.00	.04	.13
10	.02	.03	.70	.02	.01	.24	.02	.02	.43	.01	.01	.16	.01	.02	.09
11	.00	.06	1.86	.00	.01	.31	.00	.03	1.03	.00	.01	.45	.00	.05	.43
12	.02	.08	3.74	.00	.01	.45	.01	.05	2.02	.01	.01	.77	.01	.05	.70
13	.00	.01	.46	.00	.00	.07	.00	.01	.25	.00	.00	.12	.00	.01	.11
14	.02	.03	.97	.01	.00	.12	.01	.02	.52	.01	.01	.23	.01	.02	.23
15	.01	.06	2.54	.01	.01	.39	.01	.04	1.40	.01	.01	.51	.00	.04	.41
16	.01	.01	.38	.00	.00	.07	.01	.01	.21	.00	.00	.09	.00	.01	.07
17	.01	.04	.88	.01	.01	.21	.01	.02	.51	.00	.01	.20	.00	.02	.13
18	.01	.03	.46	.00	.01	.13	.00	.02	.27	.00	.01	.11	.00	.01	.07
19	.00	.01	.22	.00	.00	.05	.00	.00	.13	.00	.00	.06	.00	.00	.04

EMITTING REGION NUMBER 6

JANUARY 1980

REC NO	SO2 WET-DEP KG/HA	SO2 DRY-DEP KG/HA	SO2 CONC UG/M3	SO4 WET-DEP KG/HA	SO4 DRY-DEP KG/HA	SO4 CONC UG/M3	SLFR WET-DEP KG/HA	SLFR DRY-DEP KG/HA	SLFR CONC UG/M3	P25 WET-DEP KG/HA	P25 DRY-DEP KG/HA	P25 CONC UG/M3	P10 WET-DEP KG/HA	P10 DRY-DEP KG/HA	P10 CONC UG/M3
1	.00	.00	.04	.00	.00	.01	.00	.00	.02	.00	.00	.02	.00	.00	.02
2	.00	.01	.33	.00	.00	.06	.00	.00	.18	.01	.01	.30	.01	.03	.29
3	.06	.10	3.66	.02	.02	.57	.04	.05	2.02	.03	.02	.97	.03	.08	.73
4	.01	.11	2.68	.00	.03	.63	.00	.06	1.55	.01	.04	1.17	.00	.14	.76
5	.12	.28	7.95	.04	.06	1.51	.07	.16	4.48	.08	.06	1.99	.05	.15	1.17
6	.00	.00	.06	.00	.00	.01	.00	.00	.04	.00	.00	.20	.00	.02	.23
7	.15	.28	7.80	.06	.06	1.45	.09	.16	4.38	.03	.05	1.62	.06	.14	1.04
8	.11	.26	8.15	.05	.05	1.40	.07	.15	4.54	.05	.04	1.28	.03	.09	.73
9	.21	.38	9.69	.10	.10	2.08	.14	.23	5.54	.12	.07	2.12	.07	.18	1.16
10	.17	.32	7.61	.10	.08	1.65	.12	.19	4.35	.09	.06	1.72	.05	.13	.81
11	.00	.02	.53	.00	.00	.11	.00	.01	.30	.01	.01	.40	.01	.04	.49
12	.01	.05	1.86	.00	.01	.26	.01	.03	1.01	.00	.01	.40	.00	.03	.40
13	.00	.00	.12	.00	.00	.02	.00	.00	.07	.00	.00	.12	.00	.01	.14
14	.01	.02	.60	.00	.00	.08	.01	.01	.33	.01	.00	.19	.01	.02	.20
15	.05	.15	6.11	.02	.02	.81	.03	.09	3.32	.02	.02	.79	.01	.05	.48
16	.03	.07	1.81	.01	.01	.29	.02	.04	1.00	.01	.01	.38	.01	.02	.20
17	.07	.17	5.51	.03	.04	.96	.04	.10	3.07	.04	.03	1.27	.02	.07	.59
18	.05	.10	2.84	.02	.02	.56	.03	.06	1.61	.03	.02	.74	.02	.04	.42
19	.06	.06	1.71	.03	.01	.36	.04	.03	.98	.03	.01	.50	.02	.02	.26

Figure 5.4. Continued.

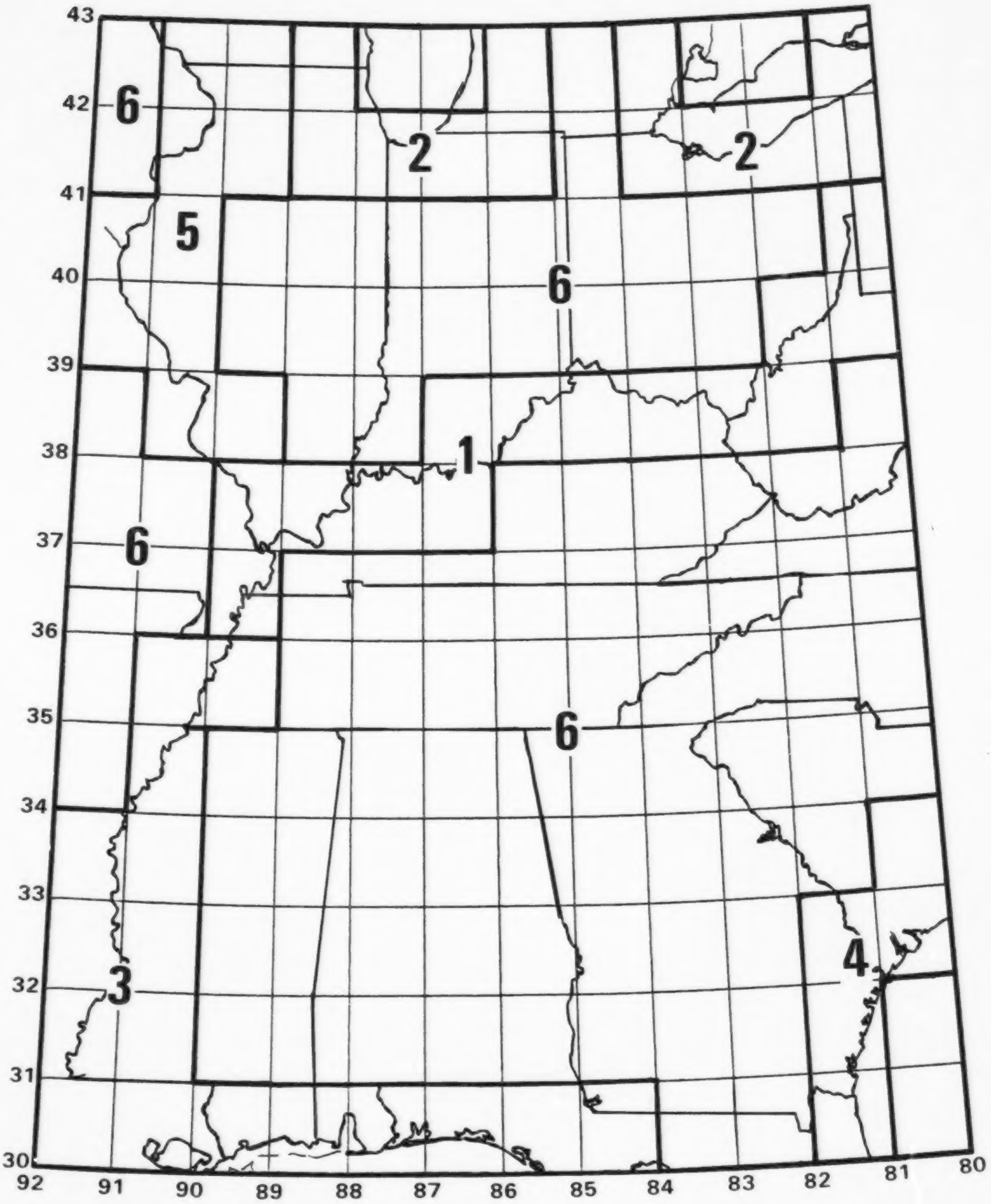
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Figure 5.5. Depiction of the six source regions used in the example execution.

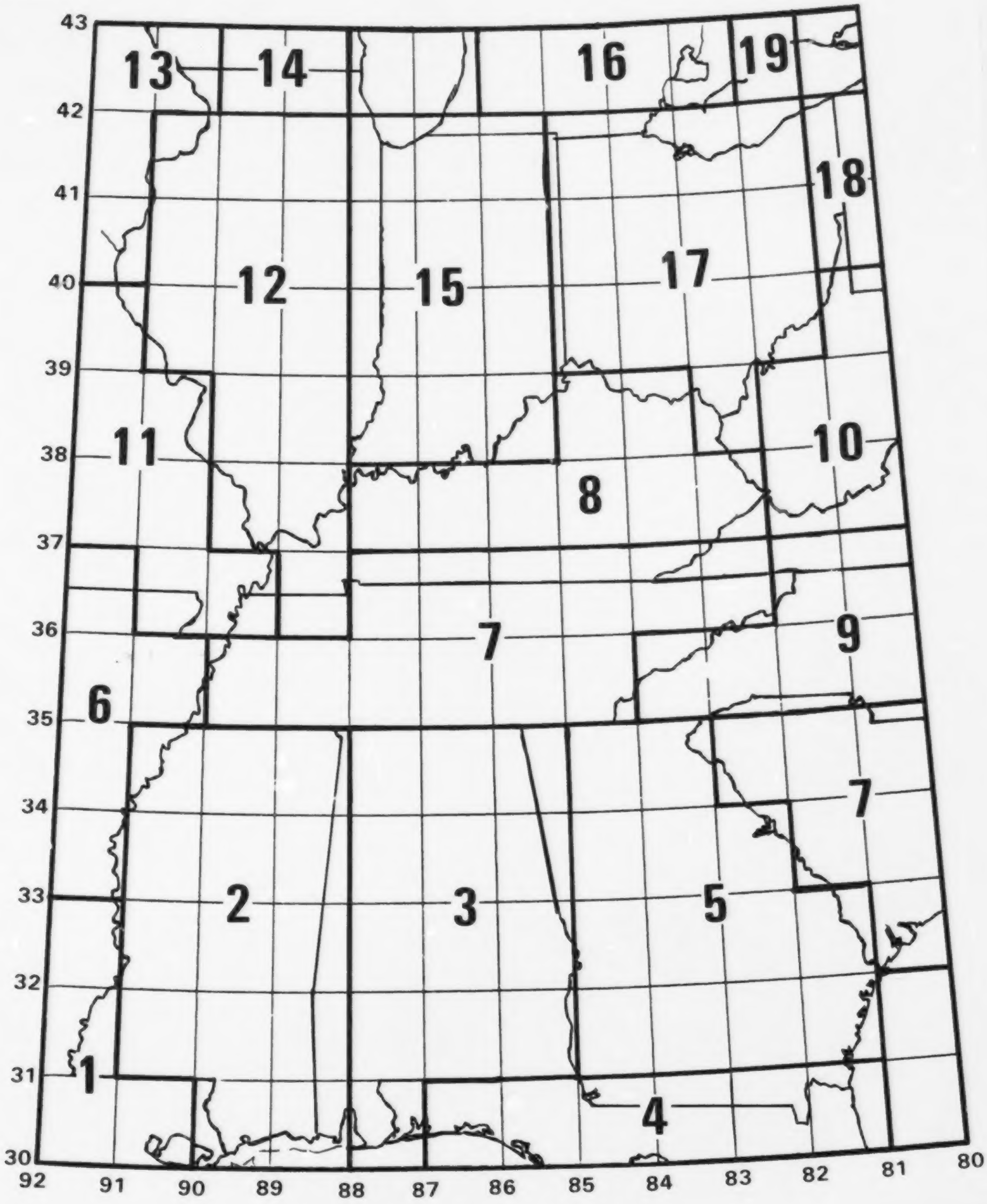
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Figure 5.6. Depiction of the 19 receptor regions used in the example execution.

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APPENDIX A

TABLE A.1. SUBROUTINES REQUIRED BY THE PROGRAMS

Program	Subroutines
PGM-TIME	ADATE*
DEPPUFP	ADATE*
WNDO-FIL	ADATE*
PGM-SFC1	ATAPE*
PGM-SFC2	ADATE*, UVGET, BARNES, GRIDZ
PGM-RAOB	ATAPE*, GROUP
PGM-RAOB2	ADATE*, UVGET, BARNES, GRIDZ
C-LOCAT	ATAPE*, ADATE*
CANRAIN	ATAPE*, ADATE*
MASTER	ATAPE*, NXDTA, AMATCH, WRITE1, BUMP, TIMEZ
LOCATR	ATAPE*
RTREV	ATAPE*, READ1, WRITE1, BUMP
GRID	ADATE*
HOLEZ	ADATE*, BARNES, GRIDZ
PACK-POINT	ATAPE*, CPUTIM, RDEMPTX
PACK-AREA	ATAPE*, CPUTIM, RDEMARX
RTREVP	none
RELMAPP	ADATE*, AFRACS**
MERGE	ADATE*
RTREVA	MATCH
RELMAPA	ADATE*, MATCH, PFRACS**
MAIN	DEFALT, FDONTM, RDEMIS, RDWEA, GENPUF, PUFMOV, XGRID, SOCHEM, PART, DPOSIT, WRTOUT, RWIND, AMATRX, PRTOUT, PRORAT, HGTADJ, DAYNIT

* UNIVAC-specific routines.
** This subroutine contains two entry points used by the programs.

APPENDIX B

OUTPUT FILE FORMAT SPECIFICATIONS FOR CERTAIN PROGRAMS

TABLE B.1. OUTPUT FILE FORMAT FOR FILE 10 OF PGM-SFC1

Variable	Description	Units	Format/Type*
AID	Station identifier	--	C
IYR	Year (last two digits)	--	I
IMO	Month	--	I
IDAY	Day	--	I
IHR	Hour	--	I
ALAT	Latitude of station	decimal degrees	R
ALON	Longitude of station	decimal degrees	R
AT	Temperature	°C	R
DPD	Dew point	°C	R
WD	Wind direction	decimal degrees	R
WS	Wind speed	knots	R
ISKY	Sky cover	%	I
IOBTM	Observation time	--	I

* C = character; I = integer; R = real.

TABLE B.2. OUTPUT FILE FORMAT FOR FILE 11 OF PGM-SFC1

Variable	Description	Units	Format/Type*
IYR	Year (last two digits)	--	I
IIMO	Month	--	I
IDAY	Day	--	I
IHR	Hour	--	I
AID	Station identifier	--	I
P	Precipitation (6-h average)	in.	R
AX	x-coordinate of station	decimal degrees	R
AY	y-coordinate of station	decimal degrees	R

* I = integer; R = real.

TABLE B.3. OUTPUT FILE FORMAT FOR FILE 10 OF PGM-RAOB

Variable	Description	Units	Format/Type*
IYR	Year (last two digits)	--	I
IMO	Month	--	I
IDAY	Day	--	I
JHOUR	Hour	--	I
IKNT	Station number	--	I
I	Level number	--	I
MTEMP	Number of levels in report	--	I
TPRES(I)	Pressure	mb	R
TGEO(I)	Height	m	R
TTMP(I)	Temperature	°C	R
TDEW(I)	Dew point	°C	R
AA	Always -9999.	--	R
XI	Longitude of station	decimal degrees	R
YI	Latitude of station	decimal degrees	R

* I = integer; R = real.

TABLE B.4. OUTPUT FILE FORMAT FOR FILE 11 OF PGM-RAOB

Variable*	Description	Units	Format/Type**
IYR	Year (last two digits)	--	I
IMO	Month	--	I
IDAY	Day	--	I
JHOUR	Hour	--	I
IKNT	Station number	--	I
NWIND	Number of levels in report	--	I
WGEO(J)	Height	m	R
WWD(J)	Wind direction	decimal degrees	R
WWS(J)	Wind speed	knots	R
X1	Longitude of station	decimal degrees	R
Y1	Latitude of station	decimal degrees	R

* IYR through WWS(J) are repeated NWIND times.
** I = integer; R = real.

TABLE B.5. OUTPUT FORMAT FOR PACK-POINT

Record Type	No. of Records	Variable(s)	Description	Units	Format/Type*
1	1	ISTATE	State	--	I2
		ICNTY	County	--	I4
		IAQCR	AQCR	--	I3
		APLID	Plant ID	--	A4
		IDATE	Date (YYDDD, DDD usually = 0)	--	I5
		IUTMZ	UTM zone	--	I2
		ANPID	NEDS point ID	--	A2
		ISICC	SIC code	--	I4
		UTMH	UTM horizontal coordinate	km	F4.1
		UTMV	UTM vertical coordinate	km	F5.1
		TLAT	Latitude	degrees	I6
		TLON	Longitude	degrees	I7
		PAT	Annual throughput	%	4F2.0
		INOR	Normal operating rate	HHDWW	I5
		SH	Stack height	ft	F4.0
		SD	Stack diameter	ft	F3.1
		ST	Stack temperature	°F	F4.0
		EFR	Exhaust flow rate	CFM	F7.0
		VEL	Velocity	ft/min	F5.0
		PH	Plume height	ft	F4.0
		IPCS	Points with common stack	--	I4
		INPP	Number of point pollutants	--	I2
		IPPID	Point pollutant ID	--	I5
		IPCE	Primary control equipment	--	I3
		ISCE	Secondary control equipment	--	I3
		ECE	Estimated control efficiency	%	F3.1
		EE	Estimated emissions	tons/year	F7.0
		IEU	Emissions units	not used	I1
		IEM	Estimation method	--	I1
		NSCCR	No. of following SCC records	--	I
2	NSCCR	ISCC	SCC ID	--	I8
		ISCCR	SCC sequence number	--	I2
		NSCCP	Number of SCC pollutants	--	I2
		**ISCCID	SCC pollutant ID	--	I5
		**EMF	Emission factor	--	F9.3
		**IEMFU	EMF units	not used	A1
		**APEM	Apportioned emission	tons/year	F7.0

---

* I = integer.

** Variables with asterisks are repeated NSCCP times.

TABLE B.6. OUTPUT FORMAT FOR PACK-AREA

Record Type	No. of Records	Variable	Description	Units	Format/Type*
1	1	JSTATE	State	--	I2
		JCNTY	County	--	I4
		JCATN	Category Number	--	I3
		JAQCR	AQCR	--	I3
		JYEAR	Year (last two digits)	--	I2
		JVML	Amount of limited access roads	miles	I6
		JVMR	Amount of rural roads	miles	I6
		JVMS	Amount of suburban roads	miles	I6
		JVMU	Amount of urban roads	miles	I6
		JNCATS	No. of following categories	--	I
2	JNCATS	KCATN	Category Number	--	I3
		KYEAR	Year of information (last two digits)	--	I2
		ITHRUP	Throughput Jan...Dec.	%	12I2
		IHPD	Hours per day	h	I2
		IDPW	Days per week	days	I1
		IWPY	Weeks per year	weeks	I2
		NPOLS	Number of pollutants	--	I2
		**JPPID	Pollutant ID	--	I5
		**POLSD	Pollutant-specific data	--	A10
		**PNAME	Pollutant name	--	A15
		**ESTE	Emission estimate	tons/year	F7.0

* I = integer.
** Variables with asterisks are repeated NPOLS times.

APPENDIX C

TABLE C.1. ERROR MESSAGES

Subroutine	Message
GENPUF	FROM GENPUF--ERROR IN PUFF FILE--IOSTAT _____ NPUFF ____ To file: #36 'SAFE-DAT' Description: An error prevented GENPUF from retaining the puff file; program stops.
MAIN	ERROR IN PUFF FILES--IOSTAT IS ___ NPUFF _____ MPUFF ____ To file: #36 'SAFE-DAT'
	ERROR IN READING PUFF FILES -- IOSTAT IS ____ NPUFF ___ MPUFF___
RDEMIS	ERROR IN READING EMISSION-FILE HEADER IOSTAT = To file: #31 TEST-LIS Description: Self-explanatory. Program stops.
	ERROR IN WRITING OUT DATA-RDEMIS IOSTAT = To file: #31 TEST-LIS Description: An error prevented the emissions data from being entered in internal format. Program stops.
	ERROR IN READING EMISSIONS FILE--PROGRAM ENDING To file: #31 TEST-LIS Description: An error prevented RDEMIS from reading the emissions file.
RDONTM	ERROR IN ROUTINE RDONTM--READING UNIT _____ IOSTAT = _____ To file: #31 TEST-LIS Description: Self explanatory. Program stops.
	ERROR IN ROUTINE RDONTM--WRITING UNIT _____ IOSTAT = _____ To file: #31 TEST-LIS Description: Self-explanatory. Program stops.
PUFMOV	PUFMOV POSITION ERROR--II or JJ
RDWEA	ERROR IN FILE __________ IOSTAT = _____ To file: #31 TEST-LIS Description: Self-explanatory. Program stops.
WRTOUT	WRTOUT--DATES DON'T MATCH _____ _____ To file: #31 TEST-LIS Description: While accumulating data from multiple emission regions, the routine checks the date-time of each entry. If the date/times from the working region don't correspond to the date/times from the previous region, an error has occurred. Program stops.

APPENDIX D

TABLE D.1. PARAMETER STATEMENT VARIABLES IN PGM-SFC1 and PGM-RAOB

Variable	Description	Units
IGX	Number of columns in domain	--
IGY	Number of rows in domain	--
JGX	One-third of IGX (rounded up)	--
JGY	One-third of IGY (rounded up)	--
MGY	Computed	--

TABLE D.2. PARAMETER STATEMENT VARIABLES IN PGM-SFC2, PGM-RAOB2, PGM-TIME, DEPPUFP, AND WINDO-FIL

Variable	Description	Units
IGY	Number of columns in domain	--
IGY	Number of rows in domain	--

TABLE D.3. PARAMETER STATEMENT VARIABLES IN RTREV

Variable	Description	Units
GLAT	Latitude of SW corner of domain	decimal degrees
GLON	Longitude of SW corner of domain	decimal degrees
IGX	Number of columns in domain	--
IGY	Number of rows in domain	--
XINC	Width of one grid cell	degrees of longitude
YINC	Height of one grid cell	degrees of latitude

TABLE D.4. PARAMETER STATEMENT VARIABLES IN CANRAIN

Variable	Description	Units
XLON	Latitude of SW corner of domain	decimal degrees
XLAT	Longitude of SW corner of domain	decimal degrees
XINC	Width of one grid cell	degrees of longitude
YINC	Height of one grid cell	degrees of latitude
IIX	Number of columns in domain	--
IIYC	Number of rows in domain	--

TABLE D.5. PARAMETER STATEMENT VARIABLES IN GRID

Variable	Description	Units
NX	Number of columns in domain	--
NY	Number of rows in domain	--

TABLE D.6. PARAMETER STATEMENT VARIABLES IN HOLEZ

Variable	Description	Units
NX	Number of columns in domain	--
NY	Number of rows in domain	--
NNX	Computed	--
NNY	Computed	--
NXY	Computed	--

TABLE D.7. PARAMETER STATEMENT VARIABLES IN BARNES

Variable	Description	Units
IGX	Number of columns in domain	--
IGY	Number of rows in domain	--
JGX	One-third of IGX (rounded up)	--
JGY	One-third of IGY (rounded up)	--
MGY	Computed	--

TABLE D.8. PARAMETER STATEMENT VARIABLES IN GRIDZ

Variable	Description	Units
IGX	Number of columns in domain	--
IGY	Number of rows in domain	--
JGX	One-third of IGX (rounded up)	--
JGY	One-third of IGY (rounded up)	--

TABLE D.9. PARAMETER STATEMENT VARIABLES IN RELMAPP AND RELMAPA

Variable	Description	Units
IGX	Number of columns in domain	--
IGY	Number of rows in domain	--
XLL	Longitude of SW corner of domain	decimal degrees
YLL	Latitude of SW corner of domain	decimal degrees
XINC	Width of one grid cell	degrees of longitude
YINC	Height of one grid cell	degrees of latitude

TABLE D.10. PARAMETER STATEMENT VARIABLES IN AMATRX

Variable	Description	Units
IGX	Number of columns in domain	--
IGY	Number of rows in domain	--
XINC	Width of one grid cell	degrees of longitude
YINC	Height of one grid cell	degrees of latitude
AX	Computed	--
AY	Computed	--
IIX	Computed	--
IIY	Computed	--

TABLE D.11. PARAMETER STATEMENT VARIABLES IN DAYNIT AND MAIN

Variable	Description	Units
RR*	Radius of the earth	km
ACONS*	Conversion factor for changing degrees to radians	radians
GLON	Longitude of SW corner of domain	decimal degrees
GLAT	Latitude of SW corner of domain	decimal degrees
IGX	Number of columns in domain	--
IGY	Number of rows in domain	--
XINC	Width of one grid cell	degrees of longitude
YINC	Height of one grid cell	degrees of latitude
AX	Computed	--
AY	Computed	--
IIX	Computed	--
IIY	Computed	--

TABLE D.12. PARAMETER STATEMENT VARIABLES IN DEFALT AND WRTOUT

Variable	Description	Units
IGX	Number of columns in domain	--
IGY	Number of rows in domain	--
XINC	Width of one grid cell	degrees of longitude
YINC	Height of one grid cell	degrees of latitude
IGXY	Computed	--
JGXY	Computed	--
AX	Computed	--
AY	Computed	--
IIX	Computed	--
IIY	Computed	--

TABLE D.13. PARAMETER STATEMENT VARIABLES IN DEPOSIT

Variable	Description	Units
IGX	Number of columns in domain	--
IGY	Number of rows in domain	--
XINC	Width of one grid cell	degrees of longitude
YINC	Height of one grid cell	degrees of latitude
GAREA	Initial area covered by one puff	km^2
AX	Computed	--
AY	Computed	--
IIX	Computed	--
IIY	Computed	--

TABLE D.14. PARAMETER STATEMENT VARIABLES IN GENPUF, PRTOUT, AND PUFMOV

Variable	Description	Units
XLL	Longitude of SW corner of domain	decimal degrees
YLL	Latitude of SW corner of domain	decimal degrees
XINC	Width of one grid cell	degrees of longitude
YINC	Height of one grid cell	degrees of latitude
IGX	Number of columns in domain	--
IGY	Number of rows in domain	--
AX	Computed	--
AY	Computed	--
IIX	Computed	--
IIY	Computed	--

TABLE D.15. PARAMETER STATEMENT VARIABLES IN PART, SOCHEM, AND XGRID

Variable	Description	Units
XLL	Longitude of SW corner of domain	decimal degrees
YLL	Latitude of SW corner of domain	decimal degrees
XINC	Width of one grid cell	degrees of longitude
YINC	Height of one grid cell	degrees of latitude
NX	Number of columns in domain	--
NY	Number of rows in domain	--
AX	Computed	--
AY	Computed	--
IX	Computed	--
IY	Computed	--

TABLE D.16. PARAMETER STATEMENT VARIABLES IN RDEMIS

Variable	Description	Units
IGX	Number of columns in domain	--
IGY	Number of rows in domain	--
GLAT	Latitude of SW corner of domain	decimal degrees
GLON	Longitude of SW corner of domain	decimal degrees
XINC	Width of one grid cell	degrees of longitude
YINC	Height of one grid cell	degrees of latitude
IGXY	Computed	--

TABLE D.17. PARAMETER STATEMENT VARIABLES IN RDONTM, RDWEA, AND RWIND

Variable	Description	Units
IGX	Number of columns in domain	--
IGY	Number of rows in domain	--

APPENDIX E

ARRAYS OF THE U- AND V-COMPONENTS OF SURFACE AND 850-mb WINDS AND OF CLOUD COVER

U-COMPONENTS

	1	2	3	4	5	6	7	8	9	10	11	12
13	5.67	5.80	5.71	5.79	5.96	5.85	5.87	5.97	5.85	5.82	5.91	5.82
12	4.79	4.75	4.87	4.97	4.99	5.05	5.12	5.10	5.13	5.15	5.12	5.13
11	4.48	4.51	4.53	4.70	4.85	4.76	4.86	4.97	4.88	4.91	5.00	4.91
10	4.10	4.19	4.14	4.28	4.44	4.37	4.47	4.59	4.51	4.53	4.65	4.56
9	2.78	2.69	2.87	3.02	2.99	3.13	3.28	3.23	3.34	3.41	3.33	3.41
8	2.36	2.27	2.42	2.64	2.64	2.73	2.91	2.89	2.96	3.05	3.03	3.06
7	2.07	2.10	2.11	2.30	2.42	2.43	2.60	2.69	2.67	2.74	2.81	2.78
6	1.00	.91	1.10	1.30	1.29	1.45	1.67	1.64	1.76	1.85	1.78	1.86
5	.67	.51	.75	1.03	.96	1.15	1.41	1.35	1.49	1.58	1.49	1.60
4	.58	.56	.65	.88	.96	1.05	1.28	1.34	1.39	1.48	1.50	1.52
3	.13	.07	.22	.48	.53	.66	.93	.99	1.06	1.19	1.19	1.22
2	-.02	-.14	.06	.39	.39	.54	.88	.90	.98	1.13	1.13	1.16
1	.02	-.03	3.59	.38	.45	3.82	.86	.92	.98	1.12	1.14	1.16

V-COMPONENTS

	1	2	3	4	5	6	7	8	9	10	11	12
13	-.04	.01	.09	.45	.67	.71	1.03	1.21	1.16	1.27	1.38	1.30
12	-.44	-.46	-.31	-.03	.06	.18	.48	.55	.61	.75	.76	.77
11	-.60	-.63	-.52	-.18	-.05	-.02	.31	.47	.42	.57	.69	.61
10	-.75	-.72	-.67	-.43	-.28	-.25	.02	.17	.15	.28	.40	.33
9	-1.34	-1.39	-1.28	-1.13	-1.13	-1.00	-.79	-.80	-.68	-.56	-.60	-.54
8	-1.53	-1.60	-1.50	-1.34	-1.37	-1.25	-1.04	-1.05	-.96	-.82	-.82	-.79
7	-1.65	-1.64	-1.62	-1.49	-1.44	-1.40	-1.23	-1.16	-1.14	-1.04	-.97	-.99
6	-2.08	-2.12	-2.04	-1.96	-1.97	-1.89	-1.77	-1.79	-1.70	-1.64	-1.68	-1.62
5	-2.21	-2.28	-2.18	-2.09	-2.15	-2.04	-1.92	-1.99	-1.87	-1.81	-1.68	-1.30
4	-2.23	-2.24	-2.21	-2.12	-2.11	-2.06	-1.95	-1.94	-1.90	-1.85	-1.85	-1.83
3	-2.37	-2.39	-2.34	-2.26	-2.23	-2.19	-2.09	-2.07	-2.04	-1.99	-1.99	-1.98
2	-2.41	-2.45	-2.39	-2.27	-2.26	-2.22	-2.10	-2.03	-2.06	-2.01	-2.00	-2.00
1	-2.40	-2.41	-2.37	-2.28	-2.25	-2.21	-2.11	-2.08	-2.06	-2.01	-2.00	-2.00

UPPER U-COMPONENTS

	1	2	3	4	5	6	7	8	9	10	11	12
13	29.22	29.29	29.30	29.56	29.77	29.77	30.06	30.27	30.13	30.09	30.11	30.05
12	28.69	28.67	28.75	28.89	28.90	29.06	29.37	29.46	29.50	29.60	29.57	29.58
11	28.51	28.54	28.52	28.63	28.65	28.76	29.17	29.38	29.29	29.42	29.49	29.44
10	28.28	28.33	28.26	28.35	28.43	28.48	28.80	29.01	28.99	29.16	29.27	29.22
9	27.48	27.44	27.45	27.41	27.29	27.49	27.83	27.87	28.08	28.42	28.49	28.52
8	27.27	27.27	27.22	27.07	26.83	27.12	27.53	27.53	27.75	28.24	28.40	28.36
7	27.07	27.09	26.99	26.93	26.88	26.98	27.31	27.46	27.60	27.99	23.19	28.16
6	26.47	26.42	26.41	26.34	26.23	26.39	26.72	26.77	27.03	27.49	27.62	27.66
5	26.31	26.27	26.27	26.13	25.88	26.17	26.56	26.48	26.81	27.42	27.59	27.57
4	26.25	26.24	26.19	26.15	26.08	26.21	26.55	26.64	26.86	27.32	27.50	27.51
3	26.05	26.03	26.02	26.01	25.98	26.10	26.47	26.61	26.79	27.25	27.45	27.44
2	26.01	26.00	25.99	25.97	25.88	26.05	26.51	26.61	26.76	27.34	27.57	27.48
1	26.01	26.00	25.98	26.00	25.97	26.10	26.49	26.63	26.79	27.27	27.45	27.43

```
UPPER V-COMPONENTS
      1      2      3      4      5      6      7      8      9     10     11     12
13 -1.09  -1.10   -.88   -.29   -.04    .17    .86   1.13   1.16   1.42   1.54   1.48
12  -.99  -1.03   -.81   -.32   -.16    .07    .64    .80    .89   1.11   1.14   1.15
11 -1.03  -1.23   -.89   -.31   -.27   -.03    .61    .79    .79   1.02   1.09   1.06
10  -.82   -.90   -.67   -.25   -.14    .05    .52    .67    .70    .88    .95    .92
 9  -.21   -.23   -.14    .10    .19    .26    .43    .46    .51    .55    .51    .55
 8  -.06   -.23    .00    .24    .21    .32    .42    .38    .45    .44    .37    .43
 7   .36    .23    .40    .49    .44    .50    .51    .47    .47    .44    .40    .42
 6  1.57   1.70   1.48   1.23   1.20   1.06    .75    .67    .60    .41    .33    .35
 5  2.01   2.19   1.90   1.47   1.43   1.27    .82    .69    .66    .38    .23    .32
 4  2.19   2.20   2.07   1.68   1.51   1.38    .96    .80    .73    .48    .36    .39
 3  2.92   3.03   2.71   2.17   2.04   1.79   1.21   1.06    .92    .60    .52    .50
 2  3.21   3.44   3.03   2.29   2.23   1.97   1.25   1.13   1.01    .62    .52    .53
 1  3.12   3.21   2.93   2.32   2.15   1.92   1.29   1.13   1.00    .66    .56    .56
```

```
SKY-COVER
      1      2      3      4      5      6      7      8      9     10     11     12
13  5.24   5.24   5.32   5.52   5.60   5.69   5.94   6.02   6.06   6.16   6.18   6.19
12  5.25   5.25   5.33   5.54   5.62   5.70   5.96   6.05   6.08   6.19   6.23   6.22
11  5.23   5.19   5.29   5.56   5.63   5.69   6.00   6.11   6.10   6.22   6.28   6.25
10  5.24   5.24   5.32   5.54   5.63   5.71   5.97   6.06   6.09   6.20   6.24   6.23
 9  5.22   5.21   5.30   5.53   5.62   5.70   5.93   6.01   6.04   6.16   6.19   6.18
 8  5.19   5.12   5.26   5.55   5.63   5.68   5.95   6.05   6.03   6.16   6.23   6.18
 7  5.23   5.21   5.31   5.52   5.61   5.67   5.89   5.96   5.98   6.09   6.14   6.12
 6  5.31   5.31   5.37   5.52   5.57   5.63   5.77   5.81   5.85   5.93   5.95   5.96
 5  5.32   5.27   5.36   5.53   5.55   5.60   5.74   5.76   5.80   5.89   5.91   5.91
 4  5.40   5.38   5.44   5.54   5.57   5.61   5.72   5.75   5.77   5.84   5.87   5.87
 3  5.56   5.59   5.57   5.59   5.61   5.62   5.66   5.66   5.69   5.74   5.75   5.76
 2  5.63   5.67   5.63   5.62   5.63   5.62   5.64   5.62   5.66   5.72   5.72   5.73
 1  5.62   5.64   5.62   5.62   5.62   5.62   5.64   5.64   5.67   5.71   5.72   5.73
```

Date ____________________

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I would like to receive future revisions to the RELMAP User's Guide.

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